PART

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ENERGY TECHNOLOGIES

Options for Prince Edward Island

Part One

COPTHORNE MACDONALD

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Department of
Energy and Forestry

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To the Student

This book has two aims. The first is to help you get more familiar with energy—its nature, its forms, and the central role it plays in our lives and world. The second aim is to help you appreciate the complex, interconnected nature of our world, and develop wise ways of dealing with that complexity.

Most people see the world as a hodgepodge of separate, disconnected items and events. The structure of our language reinforces this way of seeing. We say that some things (the subjects) do things (the verbs) to other things (the objects). We also use language to partition human knowledge. We speak of history, social studies, science, and the subdivisions of science as though they were totally separate from each other. This way of seeing is simple, direct, and often useful. But in other situations it turns out to be too simple, and quite damaging.

The truth is that we humans are an integral part of a complex, interconnected web. Many of the connections are not obvious, and many people of my generation (and prior generations) ignored them. People focused their attention on "isolated" problems, and often solved them. But the problems weren't really isolated, and the very actions that solved one problem often created others.

This narrowly-focused approach is no longer acceptable. Through our near-sighted perception of reality we have polluted our environment, depleted our resources, overcrowded our planet, and tampered with many natural processes. To build a better world, your generation will need a new way of looking—a way that sees connections, and finds defect-free solutions and long-term, whole-world answers.

I hope that this course and this book will interest you in developing that deeper, broader, more complete way of seeing and experiencing reality. And, because energy is the foundation of the physical world and involved in every action, I hope that you will get interested in energy. If you do, feel free to use the provincial Department of Energy and Forestry as a resource. You'll find people there who have the broader view. They share the aims of this course, and have worked hard to help bring it to you.

Copthorne Macdonald

PART

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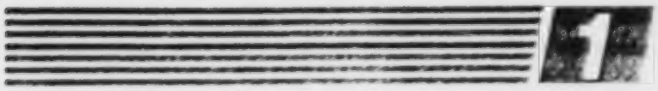
CHAPTER



THE ISLAND ENERGY SITUATION

People the world over need energy, both for survival and to make life more enjoyable.

Minimum Energy Needs

The world's five billion people are clustered today in many social and national groups. Different societies use different means to provide for the sustinence and comfort of their members. These means, these tools, these ways of getting things done have been defined as a society's *technologies.* People talk about low, intermediate, and high technology, and classify societies by level of technology.

Ninety-nine per cent of human existence has been spent in "hunter/gatherer" societies. There are still societies like this in the world, and they use low-level technologies such as simple hand tools and open fires. Industrial societies like Canada are recent arrivals on the human scene. They employ high technologies like motorized transportation, electronic communication, and automated manufacturing. There are also many societies that fall between these extremes. In developing countries like India, for example, there is a mix of high and low technologies, and also an intermediate level characterized by tools such as bicycles, animal-drawn plows, hand-operated water pumps, and hand looms.

Where people live in hunter/gatherer societies and warm climates, they consume little energy. Yet even in these situations, they must consume some. The human body generates heat energy, mechanical energy, and a little sound energy. That energy comes from the food we eat. Each person must consume from 5000 to 18 000 kilojoules (kJ) of food energy each day to supply the body's energy output and maintain constant body weight. If we convert joules into more familiar energy units, we find that one person's annual food energy intake is 500 to 1800 kilowatt-hours (kWh)—that's roughly the energy one 60 to 200 watt light bulb consumes in a year of continuous use.

If a person's food energy input is less than their energy output, they lose weight. (The body consumes its own tissues to provde the extra output energy.) If the deficiency is prolonged, activity declines. If it is severe enough and prolonged enough, the person dies. Famine and starvation are, among other things, energy problems.

Even in low-technology societies, some additional energy is needed beyond just basic food energy. Certain foods must be cooked, for example, and cooking requires energy. The amount of energy needed each day to cook one person's food varies. But let's assume that an hour of heat from a small stove burner would, on average, be enough. This adds up to about 500 kWh per year. Thus, even if their homes don't need heating, people need between 1000 and 2300 kWh per year of food and cooking energy just to survive.

Energy Units

Energy is measured in a variety of units, but here we will use metric-system units: the **joule** (J), and units closely related to the joule—the **watt-second** (Ws), **watt-hour** (Wh) and **kilowatt-hour** (kWh). A joule is defined as the work done when a one newton force is applied over a distance of one metre. It is also the amount of energy involved when a power of one watt is applied for period of one second. One watt-second, therefore, equals one joule. One watt-hour equals 3600 joules. One kilowatt-hour equals 3.6 million joules.

One joule is—

- the energy required to lift an orange from the floor to your desk top,
- the energy needed to run your portable cassette recorder for 1 second,
- the energy required to raise the temperature of 1 gram of water ¼°C,
- the energy content of 20 micrograms of gasoline,
- the energy content of 30 micrograms of butter,
- the kinetic energy possessed by a 125 gram ball travelling at 4 m/s (14.4 km/h).

Canada's Energy Needs

If we divide Canada's total annual energy consumption by the number of Canadians, we get a per capita consumption figure of 65 000 kWh. This is 28 to 65 times the per capita consumption in the hunter/gatherer example we just looked at. There are reasons for this much greater energy use—reasons having to do with our harsher climate and our more complex society:

1. To survive cold Canadian winters we heat our homes. Residential heating accounts for about 10 000 kWh per person, or 15 per cent of total Canadian consumption.
2. The food consumed by most Canadians is grown on farms, not hunted and gathered in the wild. Modern agriculture requires substantial energy inputs, including tractor fuel, livestock feed, barn lighting and heating, and the energy used to produce fertilizers and pesticides.
3. In Canadian society, an industrial sector has come into being. It manufactures tractors, fertilizers, and the ten thousand other things that contribute to material well-being and personal comfort in a developed country such as ours. Such industries use energy.
4. The products of factories and farms must reach the people who need them. A large network of commercial and transportation organizations, facilities, and equipment exists to distribute these products. Commerce and transportation systems consume energy too.
5. Governments at local, provincial, and federal levels help this complex society of ours to function smoothly. But governments, too, require considerable energy in the form of electricity, heating fuels, and transportation fuels to carry out their many activities.
6. Ours is a high-waste society, a society of disposables, a society dedicated to convenience and replacement. We throw energy away, we waste it.

Figure 1.1 illustrates how energy consumption in Canada, and in Prince Edward Island, is divided among activities.

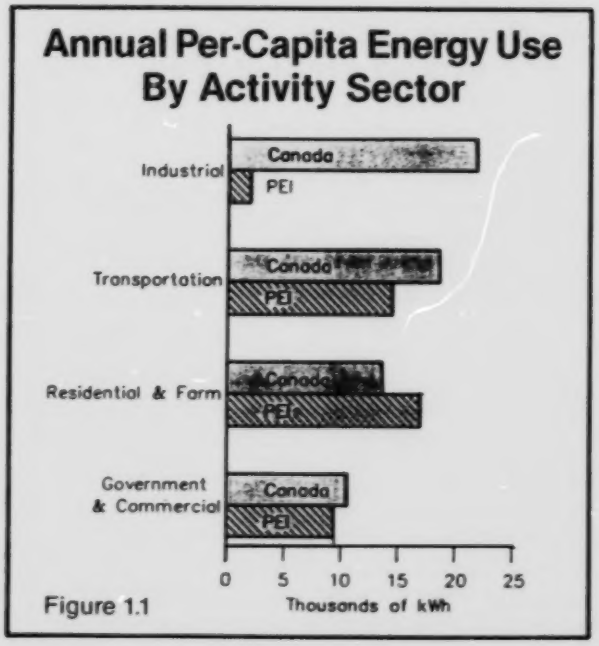


Figure 1.1

The annual per capita energy consumption of Prince Edward Islanders is only 65 per cent of the Canadian average—in part because we have less industry here.

The Canadian situation is not unique. Per capita energy consumption is high in all industrial nations. In contrast, energy consumption in all of the poorer, less-developed nations is low. This higher consumption results from the *energy-intensive* nature of many of the goods and activities associated with a high material standard of living. The list includes useful things like making automobiles and driving them. And it includes flagrant waste like putting fast-food hamburgers in plastic cases that are thrown away just seconds later.

Prince Edward Island's Energy Needs

The annual per capita energy consumption of Prince Edward Islanders is 42 500 kWh, about 65 per cent of the Canadian average. Much of this difference occurs in the industrial sector. P.E.I. has much less industrial activity per capita than the country as a whole, and the industries it does have are less energy intensive. The energy used for industrial purposes on P.E.I. is only 2040 kWh per person—about 10 per cent of the Canadian average.

As Figure 1.2 indicates, oil (and oil-based products such as gasoline, diesel fuel, kerosene, and propane) accounts for three-fourths of the energy consumed on P.E.I. The Island has no producing oil or gas wells, and all the petroleum consumed here must be brought in from other provinces or other countries. All coal is imported too. So is almost all of the electricity we use. The only locally available fuels are biomass fuels—cordwood, wood chips, wood waste, straw, and garbage.

Imported Energy Has Negative Effects

The need to import a large percentage of the energy we use has a negative impact on the P.E.I. economy. To keep our homes and offices warm and lighted requires a continuous outward flow of dollars. This creates employment elsewhere, but drains dollars away from the Island economy. *P.E.I. currently imports over 100 million dollars worth of energy every year.*

Another negative impact is the pollution created when fossil fuels are burned. Almost all coal and oil contains sulphur, and this sulphur combines with oxygen during combustion to form oxides of sulphur (SO_2 and SO_3). These oxides combine with water to create sulphurous and sulphuric acids (H_2SO_3 and H_2SO_4). The resultant product—acid rain—harms life in lakes and forests.

All the petroleum consumed here must be brought in from other provinces or other countries.

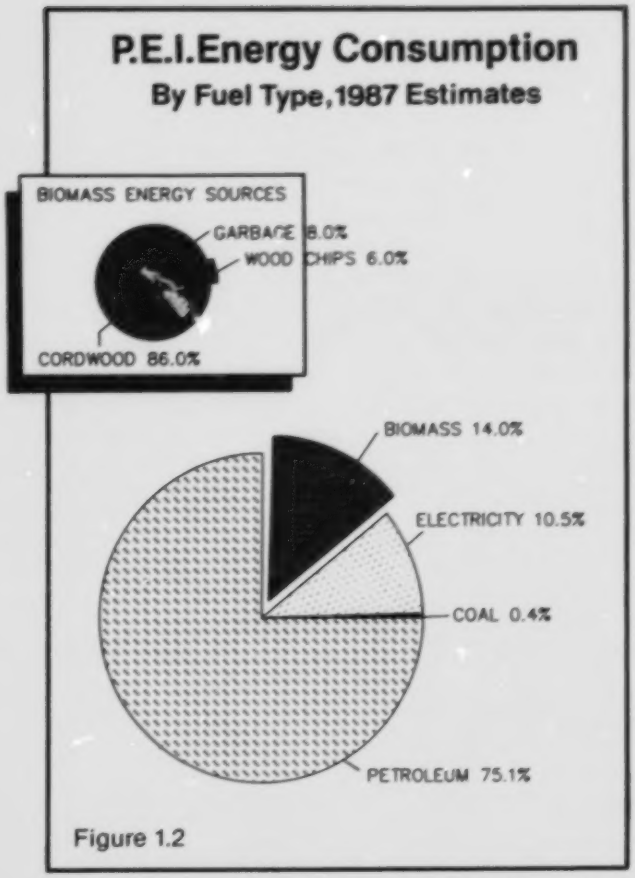


Figure 1.2

Oil (and oil-based products such as gasoline, diesel fuel, kerosene, and propane) accounts for three-fourths of the energy consumed on P.E.I.

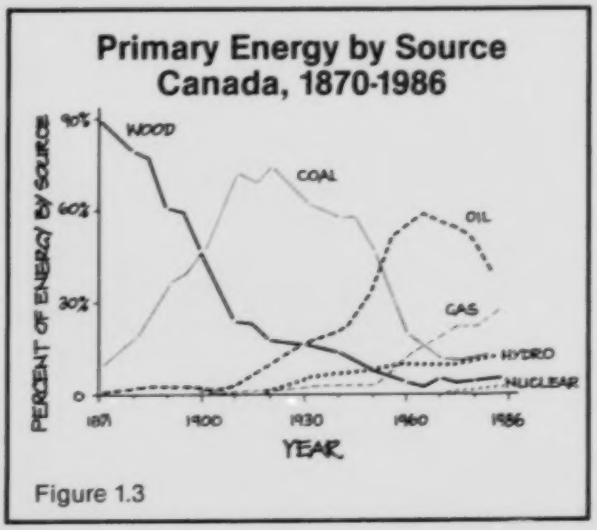


Figure 1.3

There Are "Home-Grown" Ways to Improve the Situation

There are things that we, as individual Prince Edward Islanders and as a society, can do to improve our energy situation. We have, in fact, already been doing some of them. The Island has achieved a national and international reputation for some of the work that has been going on here in energy conservation, district heating, and the harnessing of renewable energy sources — particularly biomass energy sources. In the coming chapters we will look at several possibilities for reducing our dependence on imported oil and electricity. Some of these possibilities fit our situation well; some do not. But it's important that we consider all the options, and figure out which ones make the most sense for Prince Edward Island.

In the past, various fuels have had periods of popularity. Is the situation still changing? What do you think will happen during the next 100 years? Which energy sources will become more widely used? Which ones less?

When Sulphur Burns, Does It Really Create Acid?

It's possible to run a simple experiment and find out.

Take an empty screw-top jar having a capacity of a litre or so. Remove the lid. Lay the lid upside down on a table, and fill it about half full of water. Next, take a soft-drink cap and put 2.5 mL (½ teaspoon) of sulphur into the cap. Then, carefully set the cap onto the surface of the water. (It may float, or it may sink down far enough to rest on the lid.)

Light the sulphur with a match. The sulphur may be difficult to light, and its blue flame is sometimes hard to see in bright light. When the sulphur is lit, hold the jar lid firmly against the table with one hand and screw the inverted jar part way into the lid.

Wait until the sulphur has stopped burning and the atmosphere inside the jar has cleared. Then, holding the jar lid against the table, unscrew the jar. Remove the bottle cap and discard it. Next, screw the jar back down into the lid—tightening it this time. Shake the jar vigorously. (This brings the water into contact with any sulphur oxides that may have been deposited on the jar's inner wall.) Finally, open the jar and check the water for acidity using litmus paper or some other indicator.

Is the water acidic?

What Is Energy?

In this unit on energy we will be exploring what energy *does*, its sources, and some of the many roles that it plays in our lives. For a moment, though, let's give some thought to the more fundamental question of what energy *is*.

Unfortunately, there isn't one short, complete answer to that question. It might help, however, if we looked at three partial answers — answers from the perspectives of three different scientific disciplines.

To a cosmologist, energy is the fundamental physical reality—the stuff of which the universe is made.

Cosmologists are astronomers who study the origin and structure of the physical universe. Modern cosmologists say that at one particular instant roughly 15 billion years ago all the energy in our present universe was concentrated into a small, dense "fireball" of unimaginable temperature. The temperature was too high for matter as we know it to exist. But that initial fireball expanded and cooled. As it did, much of the initial energy "condensed" into various forms of matter. And after expanding for 15 billion years, that initial fund of energy and consequent matter has become our present universe of galaxies, stars, planets, etc.

To a physicist, energy is the ability to do work. It is fundamental capability—the capacity to do things, to change things.

Countless experiments have demonstrated the truth of the first law of thermodynamics: **Energy cannot be created or destroyed, but only changed in form.** Thus, using energy to do *work* does not involve the destruction of energy. Rather, it involves the conversion or transformation of one form of energy into another form.

Let's consider a couple of examples. The first is coasting downhill on a bicycle. At the top of the hill the bike is standing still. The energy at that point exists as energy-of-position (potential energy). As you coast down, potential energy is converted into other forms of energy. Wind, tire, bearing, and brake friction convert some of the potential energy into heat energy. The rest is converted into energy-of-motion (kinetic energy). When the bike reaches the bottom of the hill, all the potential energy has been used up. Whatever potential energy was not converted to heat has, at that point, become the kinetic energy of the speeding bike and rider. That energy, too, will eventually be converted into low level heat energy as the bike slows down and stops.

A second example is a battery connected to a flashlight bulb. Chemical energy in the battery is converted in the bulb to light and heat energy.

In both of these cases energy does *work;* in both cases energy is *conserved.*

To a biologist, energy is the activator of life. Energy enables life processes and growth to take place in plants and animals.

Each year roughly 1 000 000 000 000 (10^{15}) kilowatt-hours of solar energy is captured by living organisms such as green plants, algae, and certain types of bacteria. Some of this energy is used to fuel the life processes of these organisms. The rest is stored as chemical energy within them. This stored energy is released when these organisms are eaten by other organisms. In this way, the energy needed to sustain life is passed from simple organisms to more complex ones. (This stored energy is also released when plant and other organic material—*biomass*—is burned.)

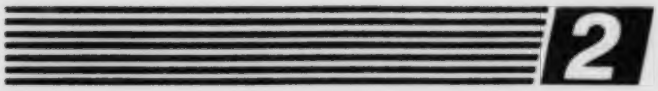
1. What is the importance of energy from the perspective of other fields of concern: Economics? Political Science? Geography? History? Nuclear Physics? Chemistry? Geology?

2. What does Albert Einstein's famous equation $E=mc^2$ tell us about the relationship between matter and energy? Can matter be converted into energy? Under what circumstances? Is matter a form of energy?

3. As poorer nations become wealthier and more developed, what impact is this likely to have on world energy resources? What could the more-developed nations do to help?

4. What changes within Canadian and P.E.I. society might reduce our present demand for energy?

CHAPTER



THE CONSERVATION OPTION

In Chapter 1 we looked at the present energy situation on Prince Edward Island. In this chapter, and those that follow, we will look at possible ways of improving it. We will, in other words, examine our energy options.

In taking this look, we should keep in mind the long-term energy situation that the whole world faces. The amount of non-renewable energy—oil, natural gas, coal, and uranium ore hidden away under the surface of the earth—is fixed, and limited. We don't know exactly how much is there. It appears, however, that most of the high quality, easily accessible deposits have already been discovered.

Supply is one side of the energy equation; demand is the other. About the future demand for energy we can be sure of two things:

- The industrial nations will want to continue a relatively high level of energy consumption.
- The developing nations will have legitimate needs for much more energy than they now use.

The long term dilemma is obvious and disturbing. *If technologically advanced societies continue to exist, and if they continue to consume fossil and nuclear fuels, the earth's supply will eventually run out. That is certain.* For this and other reasons, the energy choices that each society makes today have not only immediate consequences, but long-term consequences as well.

Evaluating Energy Alternatives

One purpose of this course is to help you learn about alternative energy technologies. Another is to help you learn to evaluate complex social issues.

Some of the energy options you will be investigating may be appropriate for Prince Edward Island. Others may not be. Part of your task in this course will be to try to separate the first from the second.

To do that you will need to go through a sensible process of data gathering, analysis, and evaluation. There is no one set method for doing this, and finding or creating a good one is something else that you and your class will be working on. As a start, consider the procedure outlined below. The words refer to energy alternatives, but the basic steps fit other situations as well.

1. **Gather the facts.** Find out what is known about the technology in question and the social situation into which it fits.
   - List the facts. List the relevant points that those who have studied the matter agree on.
   - List any missing or questionable information. Identify the things about the technology (or situation) that you still don't know, but need to know in order to make an informed evaluation.

- Try to find that missing information. If it's not available, see if there is any way to "put numbers on the guesses." Is it possible, for example, to relate the present situation to what happened when similar technologies were introduced elsewhere?

2. From the facts you have gathered, draw conclusions about what the **expected positive impacts** and the **expected negative impacts** would be if this alternative were to be implemented.

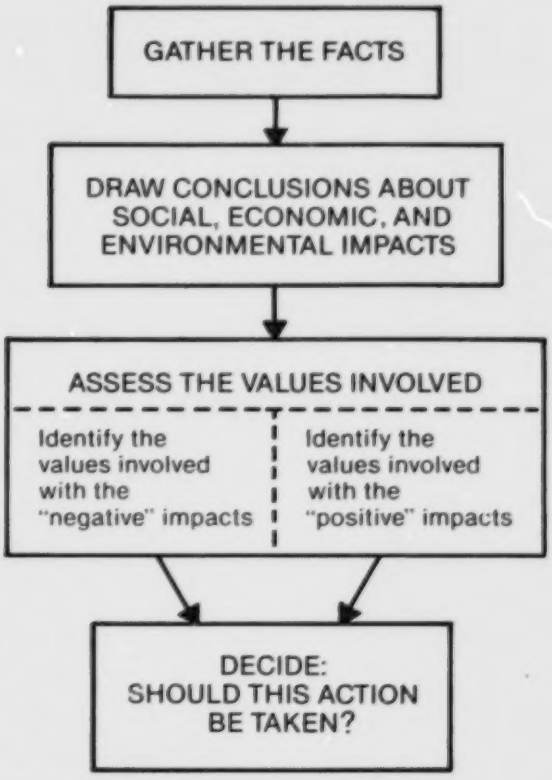
3. Consider what other impacts might *possibly* occur even though they're not expected. List the positive ones as **possible benefits,** and the negative ones as **risks.** Try to estimate the magnitude of these impacts, and the probability of their occurring.

4. When we identify certain impacts or possibilities as positive, or as negative, we are dealing with more than facts. We have then brought *values* into the assessment process—either our own *personal values,* or accepted *societal values.* This is appropriate. All decision making involves **e-valu**-ating a factual situation—applying values to the facts. But it's important to recognize what we're doing. It's important to see facts as facts, and values as values, and consider them separately. If we know that taking action A will result in consequence B, that is a matter of fact. If we maintain that consequence B is beneficial—or detrimental—that is a matter of values.

   One way to discover what the underlying values are is to explore more deeply what we really mean when we classify something as positive or negative. We need to ask some probing questions:

   - "This impact is positive, but in what sense?" (Economic benefit? Quality of life benefit? Etc.)
   - "For whom is it positive ?" (Suppliers? Consumers? Etc.)
   - We can then ask similar questions about the negative impacts and risks.

The object is to analyse each impact that you identified in steps 2 and 3 above, and list the values that underlie each. Would you expect your list to be exactly the same as those of your classmates? Why might they be different?


GATHER THE FACTS
DRAW CONCLUSIONS ABOUT SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPACTS
ASSESS THE VALUES INVOLVED
Identify the values involved with the "negative" impacts
Identify the values involved with the "positive" impacts
DECIDE: SHOULD THIS ACTION BE TAKEN?

5. You now face the difficult final question: "Would implementing this technology result in enough benefits to outweigh the risks and negative impacts?"

How do you go about assigning relative importance to each benefit, risk, and negative impact? Would your list of underlying values help? What do you do about values that conflict? Do some values have priority over other values? Is it possible to rank values in order of their importance?

And what about the risks? How do you weigh them? What makes some risks acceptable and others unacceptable?

Also, is there perhaps an implicit "controlling value" involved in making decisions that affect many people? Perhaps a value like, "Maximize benefits; minimize harm."? Or, "Benefit as many as possible, as much as possible. Harm as few as possible, as little as possible."?

Reducing Energy Consumption

One way to improve the energy situation, both locally and globally, now and later, is to cut down on the amount of non-renewable energy consumed. It's especially appropriate that we Canadians seriously consider this. We currently use more energy per capita than any other people on earth.

It is possible to *conserve* energy. Unfortunately, many people assume that energy conservation means living in cold houses and not having any fun. It needn't mean that at all. One problem is that there are two different approaches to saving energy, and people sometimes confuse the two.

The first approach involves a conscious choice to use less energy, even if this does have some impact on personal comfort and material standard of living. The second is simply to eliminate energy *waste*.

People taking the first approach have consciously decided to choose low-energy activities and products, whenever doing so doesn't involve too big a personal sacrifice. Saving energy has become one of their values. It doesn't control every decision, but it plays a part in their decision-making process along with other values. Such people may have decided to keep their houses at a lower temperature and wear sweaters. Or to walk whenever possible instead of driving. Or eat carrots raw rather than cooking them. Or fertilize their gardens with compost and manure rather than with high-energy-content chemical fertilizers.

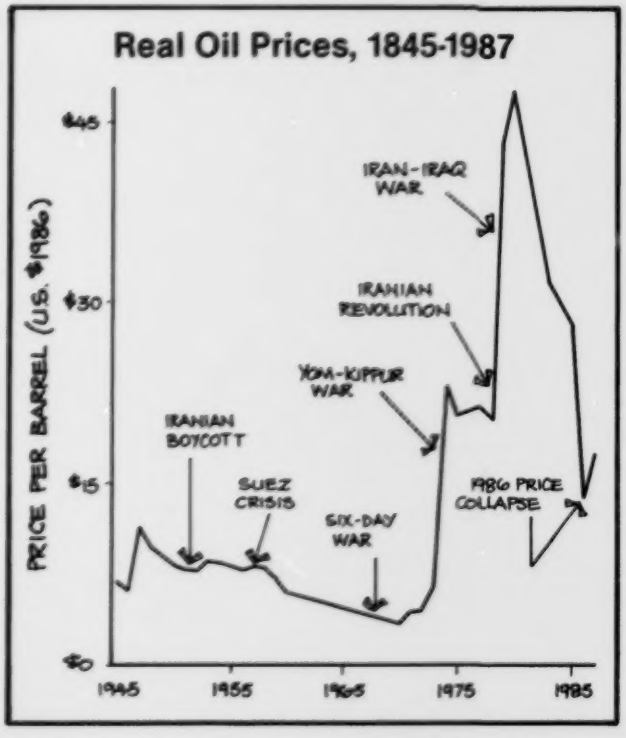
Some of these changes may have been made for other reasons, too. Overheated houses dry up nasal passages. Raw vegetables have more vitamins than cooked ones. Walking is healthful. Manure and compost are good for the soil. A high material standard of living and high energy use do seem to go together. But there are signs that society is changing its focus from "material standard of living" to "overall quality of life." This sort of change may allow—and even require—somewhat reduced energy use.

The approach just discussed involves value and lifestyle changes, and may not suit everyone. But there are no sacrifices involved in taking the second approach: cutting down the amount of energy we *waste*. Wasted energy benefits no one except the energy suppliers. When we waste energy, the bill-payer loses cash. The provincial economy loses dollars to off-Island fuel suppliers. And future generations lose fossil fuels that they might otherwise have had.

Heating Fuel Conservation

Energy conservation has been called our cheapest new energy source. New-found oil is expensive. For the most part, Canada's undeveloped liquid oil resources are in out-of-the-way places such as the ocean and the Arctic. Opportunities for saving energy, however, are close at hand, and to a much greater extent are under our own control. This is clearly the case when we consider the energy wasted in the heating of homes and other buildings.

During the 1950s, '60s, and early '70s, the price of oil was low. In 1986 dollars it was $4 to $8 Canadian per 35 imperial gallon barrel (159 L). Then, in 1973, the Organization of Petroleum Exporting Countries (OPEC) temporarily stopped shipping oil. As a result, the price of oil went up to between $20 and $25 a barrel, and stayed there after the embargo ended. The Iran/Iraq war triggered another rise in 1979, and the price rose to over $45. This oil price increase of roughly 600 per cent in just seven years triggered many changes in the industrial nations. One of these was a re-evaluation of building construction techniques and operating methods.



Dramatic oil price increases in the 1970s created worldwide interest in using energy more efficiently.

In the days of cheap oil, before 1973, most homes and commercial buildings were designed in such a way that heat leaked out fairly quickly. The object was to minimize the initial *capital cost* of the building.. Oil was cheap, and people were not yet concerned about leaving some fossil fuels in the ground for their great-grandchildren. Builders compensated for the heat leakages by installing big furnaces that burned lots of oil.

By the late 1970s, however, most buildings were being designed to take high-cost energy into account. The economics had changed. Now it made sense to spend more in the beginning, and build a building that leaked its heat more slowly. In the long run, the higher initial cost was more than compensated for by lower yearly fuel costs.

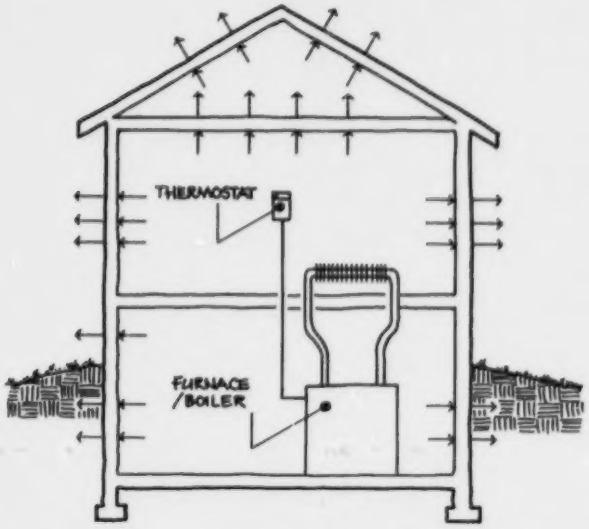
During the late '70s and early '80s, not only were new buildings more energy-efficient, but also people were improving old buildings. Throughout the early '80s the price of oil stayed high, and this was a big incentive. In 1985, however, the price dropped sharply, and remained well below the levels reached in the early-'80s. As a result, the interest in making energy-saving changes to old buildings declined in the second half of the '80s.

This is unfortunate because energy prices are sure to rise again to their former levels—and higher. Estimates of when this will occur range from quite soon to as long as 30 years from now. It is sure to happen, however, as the world's easy-to-get supplies of oil are used up. Planning now and acting now with that certainty in mind just makes good sense. It appears that you and the rest of today's high school students will be faced with increasing energy costs throughout your lifetimes. That may be unavoidable. But wasting energy isn't.

Insulating Buildings

Heat escapes from buildings in various ways. One way is *thermal conduction.* When any solid material is exposed to a high temperature on one side and a low temperature on the other, heat tends to flow from the hot side to the cold. This is one inevitable effect of the second law of thermodynamics. (See box on p. 17.) The heat stops flowing only when the two sides reach the same temperature—when they reach *thermal equilibrium.* As long as there is a temperature difference, there will be a flow of heat.

In buildings, in winter, the walls conduct heat from the warm inside space to the cold outside space. As a result, the inside temperature drops. It would drop all the way down to the outside temperature if heat was not added to the inside air. (Because the great outdoors is so vast, losing heat to it doesn't warm it up appreciably. The rise in outside temperature is negligible. Thus, the equilibrium temperature which the inside heads for is the outside temperature.)



What happens in a normal, heated home is that as soon as the inside temperature drops by 2°C or so, the thermostat on the wall signals the furnace to come on. The furnace then heats the inside air back up to its former temperature. Then the furnace shuts off and the temperature, once again, starts to fall. In this manner the temperature oscillates up and down over a two degree range. On average, the furnace supplies just enough heat to replace the heat lost. Conduction and other processes take the heat away, and the furnace burns fuel to replace it.

All materials resist, retard, or slow down the flow of heat to some extent. This charcteristic is called the material's *thermal resistance.* Metals have a low thermal resistance. They are good *conductors* of heat. Materials like plastic foam have a high thermal resistance. They are good *insulators.* Most building materials (such as wood and wallboard) are somewhere in between. They are not particularly good conductors, but they're not good insulators either.

The rate of heat flow through a material can be measured. This has been done for a wide range of building materials, and some typical numbers are given in Table 2.1. Thermal resistance is given in RSI (Resistance System International) units. The meaning of these units is explained in the box that follows the table.

Thermal Resistance of Building Materials and Assemblies

Material	Thickness (cm)	Thermal Resistance (RSI)
Gypsum or plaster board	1.3	0.08
Lumber (softwood)	2.0	0.17
Plywood	1.3	0.11
Concrete	15.0	0.20
Single-glazed window		0.15
Double-glazed window		0.30
Triple-glazed window		0.50
Uninsulated wall (typical house)		1.1
Wall of R-2000 house (typical)		4.7
Uninsulated attic/roof (typical house)		1.0
Attic/roof of R-2000 house (typical)		9.0
Fiberglass bat	8.9	2.1
Fiberglass bat	14.0	3.5
Polystyrene foam sheet	2.5	0.90

Table 2.1

RSI Thermal Resistance Values

Thermal resistance was formerly designated by the letter R, and defined in British measurement units. The insulating ability of a material was referred to as its "R-value." This system is being replaced by the metric-based RSI system (Resistance System International).

The rate at which heat is conducted through a wall section depends on three factors:

- The difference between the temperature on the two sides of the wall ($T_{inside} - T_{outside}$).
- The resistance of the section to the flow of heat (RSI).
- The surface area through which the heat flows (A).

The heat loss can be expressed as an equation:

$$\text{heat transferred} = \frac{\text{temperature difference x area}}{\text{RSI value}}$$

or:

$$Q = \frac{(T_{inside} - T_{outside}) \times A}{RSI}$$

Where: Q = the heat flow (in watts)
A = the surface area being evaluated (in m^2)
T = the temperature (in degrees C)
RSI = the section's resistance to heat loss (in m^2 times degrees C per watt).

One of the accomplishments of the early 1980s was the design of "superinsulated" houses. These houses are so energy efficient that they can be heated with as little as 25 per cent of the fuel needed to heat a house of the old design. The "R-2000 House" was one such design developed in Canada. (R-2000 is short for "residential housing for the year 2000 and beyond.") Whereas the walls of an uninsulated frame house have an RSI value of about 1.1, the typical R-2000 house has walls with an RSI value of 4.0 to 6.0. An ordinary uninsulated roof has an RSI value of about 1.0. The R-2000 roof has an RSI value of 7.0 to 10.5. The rate of heat loss from these houses is so low that even body heat and "free" heat from activities like cooking make a significant contribution to the total energy needed.

This superinsulated, supersealed 'R-2000' house consumes far less fuel than houses built the usual way.

The First and Second Laws of Thermodynamics

The First Law of Thermodynamics

Two of the fundamental principles of physics are the first and second laws of thermodynamics. We are already familiar with the first. It's the law of conservation of energy: **Energy cannot be created or destroyed, but only changed in form.**

Energy has many forms:

- The kinetic energy of mass in motion.
- The potential energy of mass that is elevated.
- Heat energy.
- The many forms of electromagnetic energy (visible light, radio waves, x-rays).
- The "relativistic" $E=mc^2$ energy inherent in that common form of energy we call matter.

Energy can be transformed or converted from one form to another, but the total amount of energy in the universe never changes.

The Second Law of Thermodynamics

The second law of thermodynamics also has far-reaching implications. It's true that energy never disappears, but as time goes on, and multiple energy transformations take place, energy gradually becomes less able to do useful work. We might say that its quality declines. Some have said that it becomes less "organized." The energy is still there in some form, but there are fewer useful things that you can do with it. It has less potential to change things.

One way of stating the second law is: **In most energy interchanges, there is a decrease in the amount of energy available to perform useful work.** The same amount of energy still exists in some form, but it is no longer able to accomplish as much in real-world situations.

Whenever an energy transfer or conversion is *irreversible*, you get this reduction in energy quality. One example of an irreversible process is the movement of heat from a hotter region to a colder region until both reach the same *equilibrium* temperature. In general, all processes that move toward equilibrium are irreversible processes, and all result in a decrease in *available* energy, a decrease in energy *quality*.

The second law applies to *closed systems*, systems having no inputs or outputs. Life processes, such as plants growing from seeds, might seem to contradict the second law—but they do not. Living things are *open systems*. That is, they receive inputs and outputs from their environment, and so are really just parts of a much larger closed system. (That system includes the biosphere and the sun.) Energy quality and availability in various *parts* of a closed system can increase, but will be paid for by a decrease in the system as a whole.

If our universe continues to expand forever, the second law of thermodynamics indicates that it will undergo what some scientists have called a "heat death." Many billions of years from now all active sources of energy—stars, radioactive processes, etc.—will have delivered their energy to the larger universe. The whole universe will have reached equilibrium temperature at slightly above absolute zero (−273°C), and all active processes will have stopped.

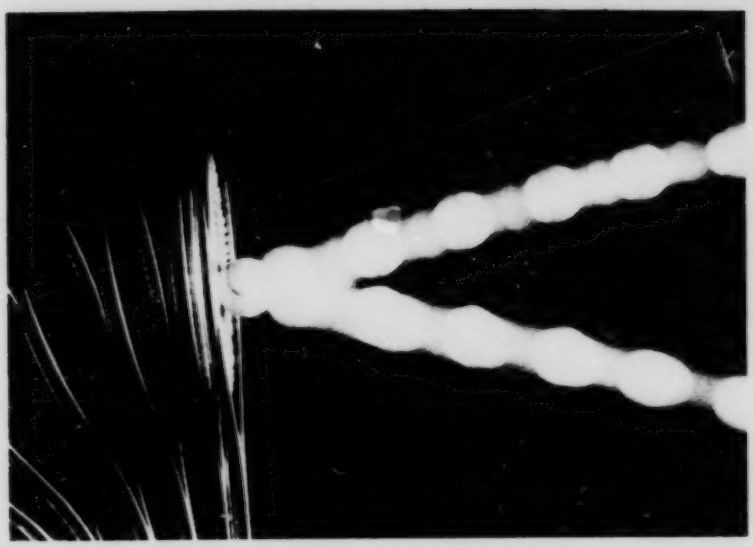
Someone once summarized the laws of thermodynamics this way:

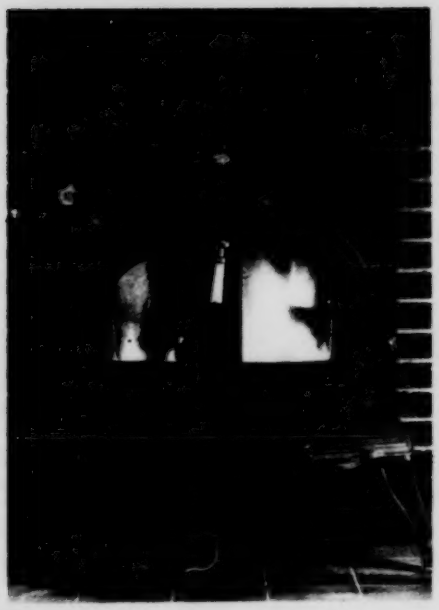
The first law says, "At best, you can only get out what you put in."

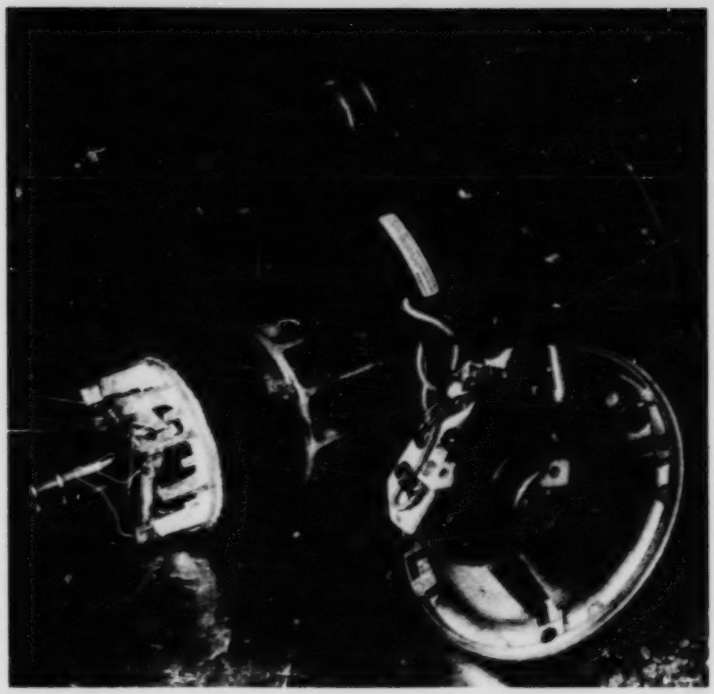
The second law says, "In the long run, you can't even break even."

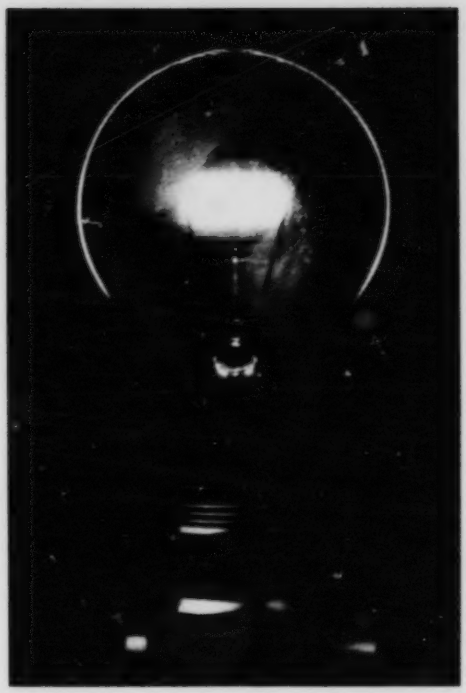
Forms of Energy

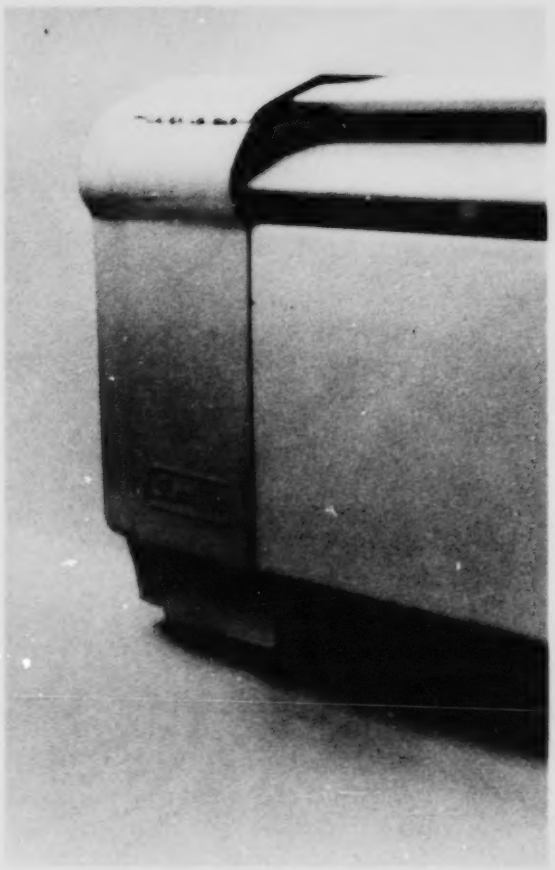
What forms of energy are present in each of these situations? (Most involve more than one form.)











CLASS DISCUSSION

Heat Conduction And Insulation

As a class, discuss the following:

1. Standing with one bare foot on a bath mat and the other on the bathroom floor we say that the floor is cold. Is the floor really colder than the bath mat? Why does it feel colder?

2. We look at two blankets on a store shelf and conclude that one is a warmer blanket than the other. If we put a thermometer against them, however, we would find that their temperatures are the same. What do we really mean when we say that one blanket is warmer than another?

3. Glass is a fairly good conductor of heat—better than wood, for example. So why is a fibreglass bat such a good insulator?

4. Do good insulators stop the flow of heat, or merely slow it down? Is there any way to completely stop the flow of heat?

5. If you put an ice cube in a spoon, the bottom of the spoon will soon become cold to the touch. Is the metal of the spoon conducting the cold of the ice cube to the hand?

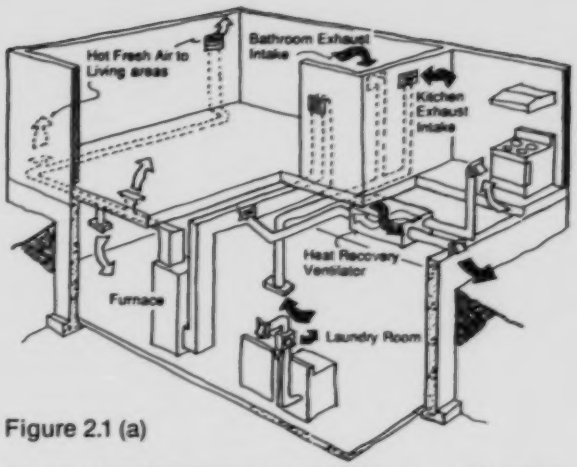


Figure 2.1 (a)

In superinsulated, supersealed homes, air is often brought into the house through a type of heat exchanger known as a heat-recovery ventilator. This device allows 50 to 80 per cent of the heat in the warm outgoing air to be transferred to the cold incoming air—thereby cutting down energy waste.

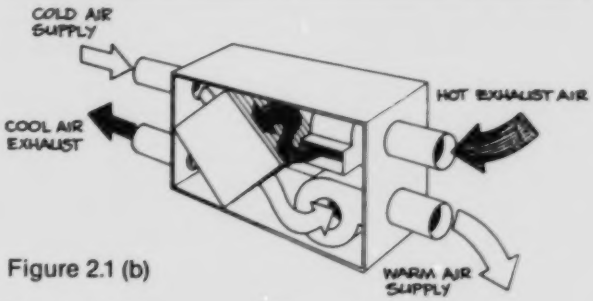


Figure 2.1 (b)

In a heat-recovery ventilator, thin aluminum or plastic membranes keep outgoing and incoming air separate from each other while effectively transferring heat from one to the other.

Reducing Air Leakage

Heat conduction through walls, window panes, and roofs is not the only way that heat escapes from buildings. It also occurs through an exchange of inside and outside air. Because people need fresh air to breathe, some loss of heat through air exchange is unavoidable. But in most homes, much more *air infiltration* exists than is necessary for health and comfort. In typical Canadian houses, leakage replaces all the warm air with cold outside air every hour or two. This cold air comes in through cracks around windows, doors, chimneys, foundations, utility entrances, and various other places. And it gets worse when the wind is blowing. Experiments on typical houses built in the mid-1970s and before indicate that 30 to 50 per cent of heating energy is lost this way.

Planting rows of trees to break the wind can be of some help, but a more direct and immediate approach is sealing up those places where the air gets into the house. Research has indicated that a moderate level of sealing will reduce fuel consumption in leaky homes by 20 to 30 per cent. Because of this, a whole new industry arose in the early '80s dedicated to cutting energy loss in existing homes by sealing air leaks.

In superinsulated houses, sealing is purposely carried to an extreme. Care is taken to surround the living space with a well-sealed air and vapour barrier under the wallboard. And the house is built with tight-fitting windows and doors. These precautions produce a house with very low air leakage.

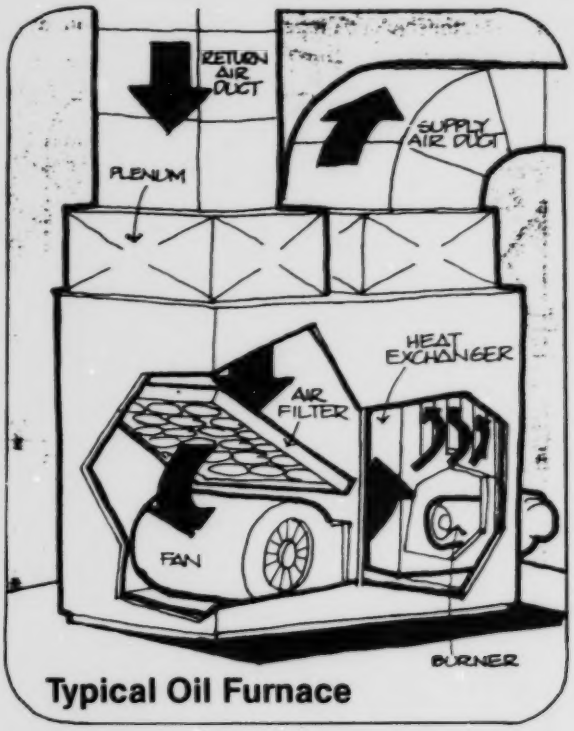
Moisture and pollution problems can arise in tightly sealed homes unless the right steps are taken. For health and comfort, fresh air is needed and stale air must be gotten rid of. It turns out that many household materials, including wallboard, plastics, and some

fabrics, give off pollutants such as formaldehyde and other organic chemicals. Radon gas may enter a house through the foundation. Also, pets, people, and household activities like cooking generate unpleasant odors. In unsealed houses the concentration of these pollutants is kept low through continuous flushing by leaked air. In superinsulated, supersealed homes, pollution can rise to unacceptable levels. This is avoided by using controlled, fan-induced ventilation. As shown in Figures 2.1(a) and 2.1(b) on p. 20, outside air is usually brought into a house through a type of heat exchanger known as a heat-recovery ventilator. This device allows 50 to 80 per cent of the heat in the warm outgoing air to be transferred to the cold incoming air—thereby cutting down energy waste.

Improving Furnace and Boiler Efficiency

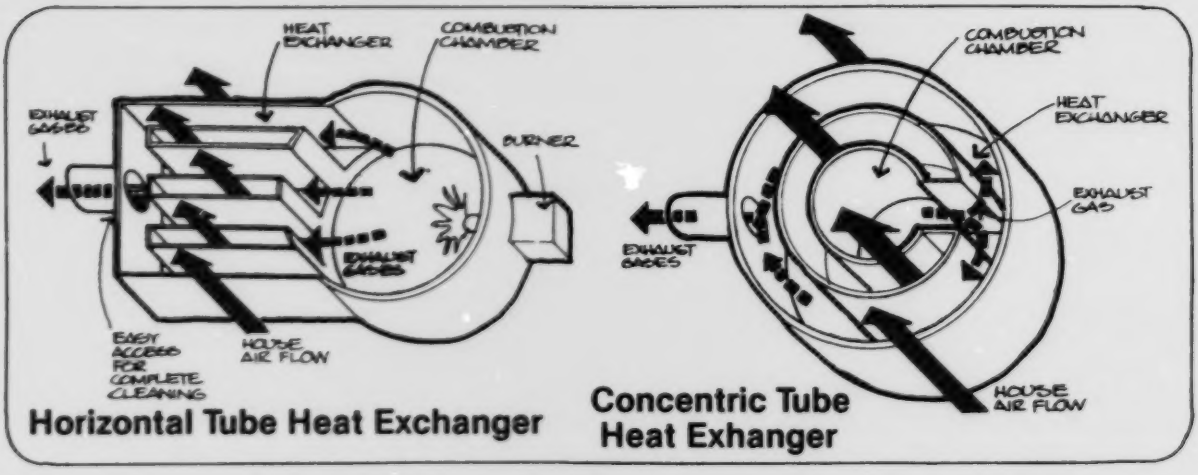
Another result of the low oil prices before 1973 was that little attention was paid to making furnaces as efficient as possible. The heating energy of a fuel is the amount of energy released when that fuel is completely burned. If a furnace could deliver all of the fuel's energy to the interior of a building, we would call the furnace 100 per cent efficient. The ratio of useful, delivered heat to the heating energy inherent in the fuel is the efficiency of the boiler or furnace.

No furnace is 100 per cent efficient. The efficiency of older oil-fired furnaces in good repair is typically 65 to 70 per cent. Newer systems, those designed in the 1980 s, are typically 80 to 85 per cent efficient. Combustion is more complete in the newer systems, and better controlled. And heat transfer from combustion to the circulating air or water is better.



Typical Oil Furnace

In a hot air furnace, heat from the combustion gases is transferred to building air in some form of heat exchanger.



Horizontal Tube Heat Exchanger

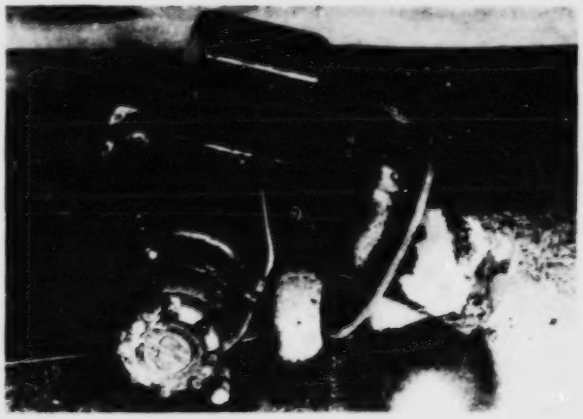
Concentric Tube Heat Exhanger

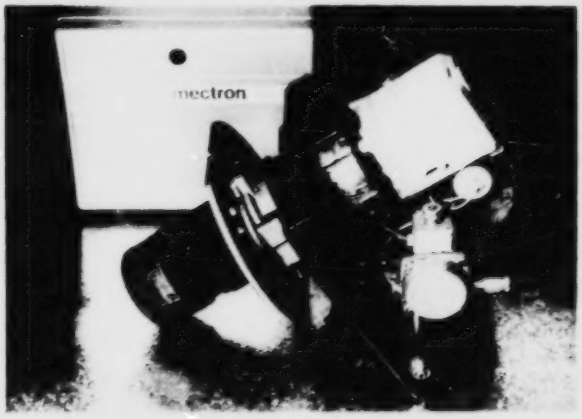
In some hot water furnaces, heat from combustion gases is transferred to the water through a jacket-type heat exchanger.

Some of these new systems include automatic flue dampers that keep warm building air from going up the chimney when the burner is off. And by delaying the flow of oil on start-up until the combustion air fan reaches full speed, soot buildup on heat transfer surfaces within the furnace is reduced.

In ordinary houses, combustion air is usually taken from the living space. Sometimes this causes drafts, since the air must ultimately come from outside. In superinsulated, supersealed houses, combustion air is brought directly into the combustion chamber from outside the house. In this way the fire gets the oxygen it needs without affecting household air.

The efficiency of some older furnaces can be greatly improved by replacing the old cast-iron oil burner with one of the newer units. In other cases, the whole furnace or boiler must be replaced.





The modern oil burner on the right is much more efficient than the older type on the left.

Electrical Conservation

Electricity is our most versatile form of energy. It can be used to power high-tech equipment such as computers and telephone systems, and it can perform mundane tasks such as cooking our food and heating our homes. It is also our most expensive form of energy. One reason for this is the low efficiency of electrical generating plants. For thermodynamic reasons, when fuel is burned to generate electricity, only about 35 per cent of it ends up as electrical energy. Ordinarily, the other 65 per cent is wasted. See the box on EFFICIENCY on p. 28. (As we will see in the upcoming discussion of electricity/heat co-generation systems in Chapters 7 and 8, there are ways to put that "waste" heat to good use.)

As we saw in Chapter 1, 75 per cent of Prince Edward Island's energy needs are met by oil and oil-based products. None of that oil is produced locally, so reducing our consumption and avoiding waste means that more dollars remain here.

Similar things can be said about electricity. For many years now, electrical energy has cost more in Prince Edward Island than in any other province. And, just as we import our oil, we also import our electricity. In recent years, up to 99 per cent of the electricity we use has been generated in New Brunswick and delivered to P.E.I. through the 138-kilovolt submarine cable that crosses the Northumberland Strait. The small amount that is generated here is generated by burning imported oil.

In recent years, up to 99 per cent of our electrical energy has come across Northumberland Strait through a 138-kilovolt submarine cable.

Reducing Unnecessary Consumption

While more can be done, we should note that Prince Edward Islanders are already the most frugal users of electricity in Canada. Electrical energy consumption per customer in the residential and farm sector is just 37 per cent of Quebec consumption, and about 50 per cent of what Ontario and New Brunswick customers use. A large part of this difference arises because many people in these other provinces heat their homes with electricity. Because of the high cost electricity on P.E.I., it's almost never done here.

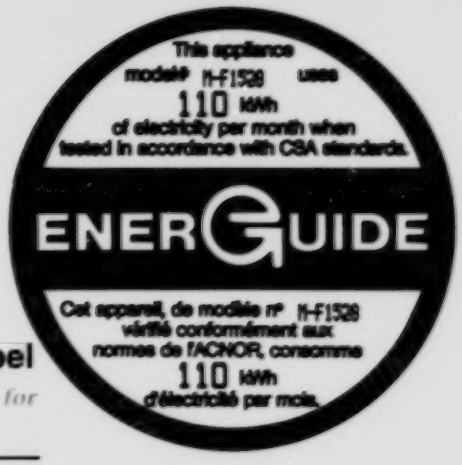
One way of conserving electricity is to use it only for those jobs which can't be done by less costly, lower "quality" forms of energy. We must have electricity to run our computers and play our CDs, but there are other ways to heat our houses and cook our food. Heating-type appliances such as stoves, hot water heaters, room space heaters, and irons are high wattage appliances. A typical stereo draws 50 watts, and a business-type personal computer draws 150. But a 40 gallon hot water heater draws 3000 watts at times, and a stove with the oven and all elements on draws about 12 000 wattts. (Remember that this is 12 000 J/s!)

Asking if a particular heating job can be done another way is a good starting point. If the job is ironing clothes, the answer may be no. But if it's heating water or cooking food, the answer may well be yes. Water can be heated more cheaply in oil- or propane-fired hot water heaters than in electric ones. And, except in air-tight houses where open flames can deplete the available oxygen and fill the house with moisture, a propane stove makes cost and energy-conservation sense. An ideal time to switch is when the old range or hot water heater needs to be replaced anyway.

Progress is also being made in making appliances more energy-efficient. Dishwashers are now being built with low-energy drying options, and the efficiency of

refrigerators increased substantially during the 1980 s. In the industrial and commercial sectors there have been increases in electric motor efficiency and the efficiency of fluorescent lighting. In all of these areas it is now possible to do the same job as before, but consume less electrical energy doing it.

Finally, there are those effective human ways of reducing energy waste that we all know about, such as turning off lights and appliances when we're through using them.



Energuide Label

Energuide labels allow you to comparison shop for energy-efficient appliance models.

CLASS PROJECT

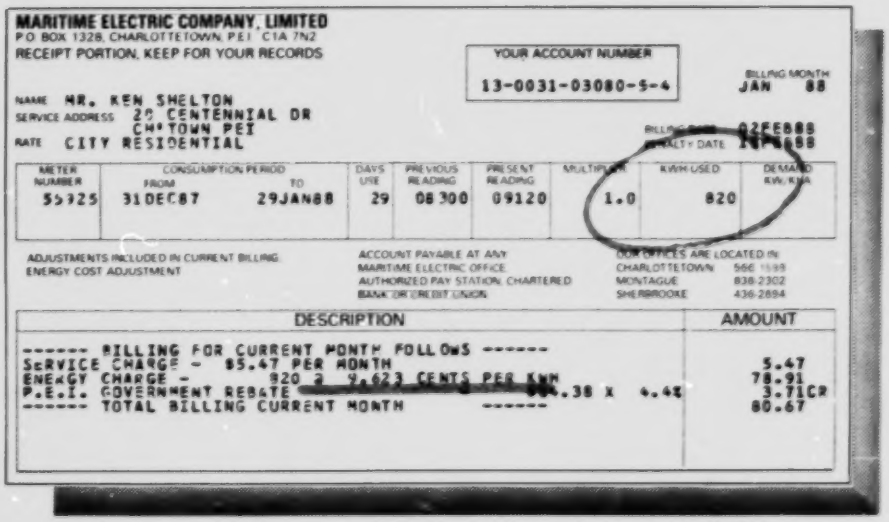
Power, Energy, and the Cost of Electricity

Power and energy are so closely related that people sometimes get them confused. But they are different, and it's important to know what that difference is.

Energy is the basic stuff, not power. Energy is fundamental physical reality. You can accumulate energy, convert it to another form, or transfer it to another place. Power, at any instant, in any situation, is simply the rate at which energy is being produced or used.

One joule is a standard quantity of energy. A power of one watt refers to an energy flow of one joule per second. (Thus, one joule can also be referred to as one watt-second.)

Electric utility companies bill residential customers for the total amount of electrical



MARITIME ELECTRIC COMPANY, LIMITED
P.O. BOX 1328, CHARLOTTETOWN, P.E.I. C1A 7N2
RECEIPT PORTION, KEEP FOR YOUR RECORDS

YOUR ACCOUNT NUMBER: 13-0031-03080-5-4
BILLING MONTH: JAN 88

NAME MR. KEN SHELTON
SERVICE ADDRESS 20 CENTENNIAL DR
CH'TOWN PEI
RATE CITY RESIDENTIAL

BILLING DATE 02FEB88
QUALITY DATE 10FEB88

METER NUMBER	CONSUMPTION PERIOD FROM	TO	DAYS USE	PREVIOUS READING	PRESENT READING	MULTIPLIER	KWH USED	DEMAND KW/KVA
55925	31DEC87	29JAN88	29	08300	09120	1.0	820	

ADJUSTMENTS INCLUDED IN CURRENT BILLING
ENERGY COST ADJUSTMENT

ACCOUNT PAYABLE AT ANY
MARITIME ELECTRIC OFFICE
AUTHORIZED PAY STATION, CHARTERED
BANK OR CREDIT UNION

OUR OFFICES ARE LOCATED IN:
CHARLOTTETOWN 566 1198
MONTAGUE 838-2302
SHERBROOKE 436-2894

DESCRIPTION	AMOUNT
------ BILLING FOR CURRENT MONTH FOLLOWS ------	
SERVICE CHARGE - $5.47 PER MONTH	5.47
ENERGY CHARGE - 820 @ 9.623 CENTS PER KWH	78.91
P.E.I. GOVERNMENT REBATE [redacted].38 X 4.4%	3.71CR
------ TOTAL BILLING CURRENT MONTH ------	80.67

Electric Bill

Your electrical bill tells you how many kilowatt hours of electrical energy were used during the billing period.

energy used each month. They could bill for so many joules (watt-seconds) used, but instead they use a larger unit: the kilowatt-hour. (1 kilowatt-hour = 3 600 000 joules. Can you verify this?)

Printed on each month's bill is a figure for the total number of kilowatt-hours (kWh) of energy consumed during that billing period. If you divide the total dollar amount of the bill by the kWh figure, you get the current cost of each kWh.

An appliance's wattage rating refers to the amount of power that the device draws from the utility when it's on. The units used are watts, or in some cases, kilowatts (kW).

Have you grasped the ideas?

With the above in mind, solve the following problems, and be prepared to discuss them in class:

1. You'd like to get a small electric heater to warm up your bedroom. You've found a nice looking 1000-watt unit in a catalogue, and the price seems reasonable. Your parents say that they'll buy the heater if you'll pay for the electricity. How much will it cost you per day to run the heater if it's on all the time? How much would that amount to per month?

2. Your dad discovered that you left a 60-watt light on when you were working in the back of the basement 5 weeks ago. It's been on ever since. He plans to take the cost of the electricity out of your allowance. How much will you lose?

3. Calculate the cost of using your favourite electric appliance for a month. Hair dryer? Stereo? TV? Other? (The appliance may have a label on the back or bottom that tells the wattage. Or if the appliance has an AC adapter unit that plugs into a wall outlet, the wattage may be marked on it. You'll also need to estimate the number of hours per month that you use the appliance.)

Since we now get much of our electricity from the mainland, this oil-burning electrical plant in Charlottetown is used less frequently than it once was.

Appliance Wattages and Typical Consumption

Appliance	Typical Wattage	Typical Monthly kWh Consumption
Blanket, electric	180	10
Can Opener	175	< 1
Clock	2	2
Clothes Dryer	4800	80
Clothes Washer (excluding hot water)	500	8
Coffee Maker	900	6
Dishwasher (excluding hot water)	1300	18
Fan, portable	115	4
Food Mixer	100	< 1
Freezer (15 ft³)	335	74
Freezer (frost-free)	425	90
Furnace Fan Motor	250	100
Furnace Oil Burner	260	50
Hair Dryer	1000	4
Microwave Oven	1150	25
Radio, solid-state	5	< 1
Range (standard)	12000	100
Refrigerator (12 ft³)	300	100
Refrigerator (frost-free)	500	150
Stereo, solid-state	30	6
Table Lamp	100	8
Toaster	1150	4
TV, 30 cm black and white	32	3
TV, 34 cm colour	70	7
TV, large screen, colour	330	33
Vacuum Cleaner	800	4
Water Heater (40 gal.)	3000	400

Electrical Load Management

It turns out that there is more to electrical conservation than just consuming fewer kilowatt-hours of energy. The time of day, day of the week, and season of the year that the power is used are important too. The problem is this:

1. Each electric utility is required to have enough capacity to meet the needs of its customers, and maintain a suitable reserve.
2. Any electrical generating system can deliver only so much electrical power to its subscribers. That limit can't be exceeded.
3. The utility never knows for sure what the electrical load on its generators will be. Users can, and do, switch equipment on and off as they wish. And they can freely go out and buy more equipment. Because of this, demand for power is always changing.

Fortunately, not all users consume large amounts of electricity at the same time. At any given moment, some loads are on and others are off. So, to some extent, things average out. Unfortunately, this averaging-out is far from perfect. There are times of the day and times of the year when many customers choose to draw power from the system simultaneously. Islanders use more electrical power in the dead of winter than in summer, for example, and more at supper time than at other times of the day.

Let's pick an example. Maritime Electric Company is the utility that serves most of P.E.I. The peak energy use on Maritime Electric's system during 1986 occurred at 6 p.m. December 11. At that hour Island customers had 113 megawatts (113 million watts) of electrical load connected to the system — almost 1000 watts for each man, woman, and child on the Island. At that hour Islanders were consuming electrical energy at a rate of 113 million joules per second. (See Figure 2.6.)

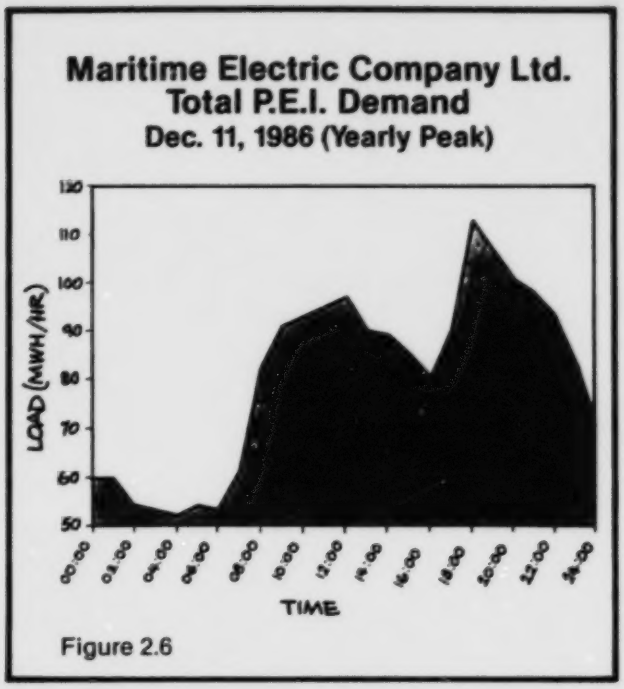


Figure 2.6

The highest energy demand during the year is likely to occur on a December day about supper time. What are some possible reasons for this?

By the rules under which electric utilities operate, the total amount of excess generating capacity which a utility must have is tied to its yearly demand peak. Electric utility companies must have at least 15 per cent spare capacity— 130 MW total capacity in our example where the peak load is 113 MW. If customers connect more electrical load, and the peak demand goes up, the utility must acquire more capacity. New capacity is expensive these days, so most utilities want to avoid this.

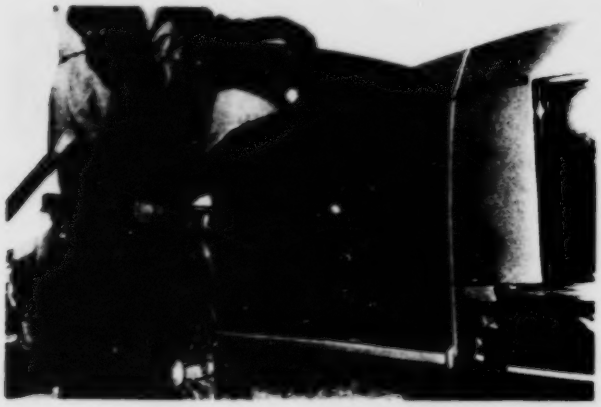
It turns out that the highest peaks occur for only a short time. The demand rises into the top ten per cent for only 100 hours during the year. Looking at this fact another way, if electrical demand could be reduced by 10 per cent during those crucial 100 hours, the utility could get by with 10 per cent (13 MW) less generating capacity. Practically speaking, since demand is slowly rising year by year, reducing the peak would mean that the utility could put off the day when it would need to purchase new generating capacity. And since 13 megawatts of new capacity costs about $26 000 000, that's an expense worth putting off.

On the residential side, some of the consumption-reducing measures already mentioned would help reduce demand — things like switching to other fuels for heating water and cooking. In commerce and industry, installing more efficient fluorescent lighting would help. And since the P.E.I. demand peaks occur during hours of darkness, improving the efficiency of Island street lighting would help too.

There is, however, another strategy for reducing peak demand. It's to move some of the electrical load to off-peak times. Water heaters, for example, might be equipped with time clocks that would shut the heating elements off during periods of peak demand. (There would still be enough *stored* hot water to handle most needs.) Office buildings could be cleaned later on in the evening, allowing their lights to be off during the peak. There might even be helpful changes in farm routines: perhaps, during the winter, cows could be milked before or after the supper-time peak. In industry, some large refrigeration systems could be turned off during the peak period. And perhaps householders could shift some of their cooking and bathing activities to other times.

Motor Fuel Conservation

On P.E.I., a third of our total energy and 45 per cent of our petroleum is used to get people and goods from one place to another. That's a lot of energy, so it makes good sense to look at the transportation sector for opportunities to cut consumption.



Improving Vehicle Efficiency

During the 1950s and '60s North Americans had a taste for big, ever-more-powerful, gas-guzzling cars. This phenomenon reached its peak in 1973 when the average new car required 16.5 litres of gasoline to go 100 km. Shortly after the 1973 oil embargo, the governments of Canada and the U.S. put pressure on automobile manufacturers to improve the gas mileage of new cars. Foreign manufacturers didn't need to be pushed, and many North American buyers switched to smaller, more energy-efficient foreign makes. Considerable progress was made, here and abroad, and by 1986 the average new car sold in Canada needed only 10.3 litres of gas to go that 100 km.

Meanwhile, trucks were also becoming more energy efficient. Both new engine designs and aerodynamic flarings on truck bodies helped to cut their fuel consumption.

Efficiency — In Engines and Elsewhere

The efficiency of any energy-converting, energy-transforming process is defined as the useful energy output divided by the energy input. The conventional symbol for efficiency is the Greek letter η (eta), and the equation that expresses efficiency in per cent is:

$$\eta = \frac{E_o}{E_i} \times 100\%$$

Where:

η = efficiency of the system
E_o = the useful energy output from the system
E_i = the energy input to the system

One of the consequences of the second law of thermodynamics is that heat-energy to mechanical-energy conversion systems (such as steam turbines and automobile engines) must always have rather low efficiencies.

Let's consider the automobile engine. The gasoline-air mixture at the top of the cylinder is ignited by a spark, and produces high-temperature heat. Some of that heat is converted into mechanical energy as the combustion-byproduct gases expand, and drive the piston toward the bottom of the cylinder. When the piston reaches the limit of its travel, the combustion gases will have expanded as much as they can. At that point, however, those gases still contain considerable heat energy. That energy might be useful for some purpose — such as indirectly heating the car interior in winter — but the engine has already extracted all the *mechanical* energy possible. At this point a valve opens, and that residual heat is exhausted to the atmosphere. Exhausted heat is an unavoidable waste product of internal combustion engines, and one that keeps engine efficiencies down in the 25 to 40 per cent range.

Electric motor efficiencies, on the other hand, can be quite high. An electric motor operates on the principle of magnetic attraction and repulsion, and exhausted heat is not one of its fundamental operating requirements. Some energy is lost in the heating of the motor's windings and bearings, but efficiencies as high as 98 per cent have been reached.

Adopting Good Driving Practices

In the mid-1970s the speed limit on U.S. highways was reduced from 104 to 88 km/hr (65 m.p.h. to 55 m.p.h.). In the mid-1980s it was raised again, but a decade of slower speed on the highway effectively demonstrated that reduced speed saves gas. It saves lives too. The highway fatality rate was also lower during this period. Slower speed, combined with smooth, gradual acceleration allows drivers to get the very best gas mileage that their cars can deliver.

Taking a Full Load

Travelling with a full load is another approach that cuts down overall transportation fuel consumption. Travelling with a full load reduces the fuel used per person, or per kilogram of cargo. The idea has taken many forms.

Commuters have set up car and van pools to enable several people to get to work in one vehicle. On P.E.I., for example, the Department of Energy and Forestry set up the Enerpool van pool program. Boston even went so far as to set aside the fast lane of one busy highway for cars containing two or more people.

These days, trucking companies make sure that their long distance trucks have full loads. And with deregulation of the airline industry, airline companies have come up with innovative fare structures which ensure that each flight is as nearly full as possible.

Avoiding Unnecessary Trips

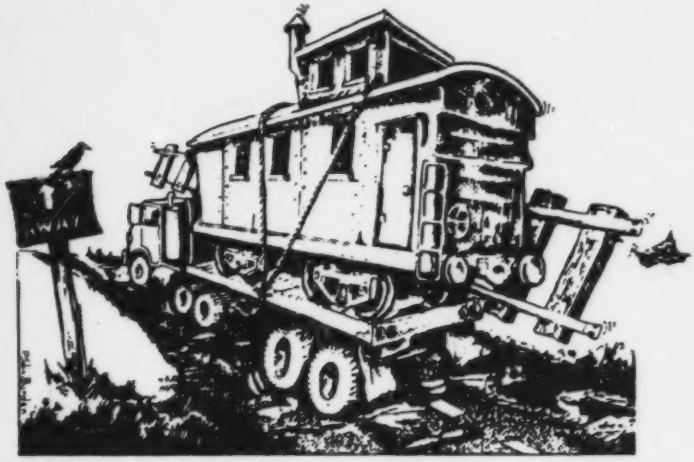
The extent to which we have become a convenience-oriented society becomes clear when we look at automobile usage habits. If there is a car sitting in the driveway, the tendency is to hop into it every time there is an errand to run. Most of the time, a little advance planning would allow us to accomplish several things on one trip. This would save energy—and time too.

Van pools enable several people to get to work in one vehicle. Passengers pool resources and so save money and fuel.

ROLE PLAY

The Vanishing Railroads

Prince Edward Island—like many other places—is losing its railroads. Do a role play on this issue, with individual students taking on the roles of a farmer, an ecologist, a bicyclist who wants the roadbeds used for bike paths, a railroad buff, a railroad executive, the civil servant responsible for highway repair, etc. Let each one talk about what the loss of the railroad means to her or him.



PROBLEMS/QUESTIONS

1. To keep their house warm, the Willis family burns 3000 litres of oil a year. They recently had their furnace tested and found out that it is 65 per cent efficient. If they replace it with a unit that is 85 per cent efficient, how much oil will they save each year?

2. What steps can be taken to improve the efficiency of an existing oil furnace?

3. Turning the thermostat down at night saves energy. Discuss why this is so, using the RSI heat flow equation in your explanation.

4. Airlines give lower prices to people who book their flights in advance and agree not to change their plans. How does this help to keep planes full? Discuss the pros and cons of last-minute standby fares. If students could get cheap fares by flying standby would it help fill planes? What might happen if cheap standby flights were available to everyone?

5. Using steps 1 and 2 of the procedure in the EVALUATING ENERGY ALTERNATIVES box, come up with a list of positive and negative impacts that would occur—or might occur—if Islanders got very serious about conserving energy.

CHAPTER

3

WIND, SOLAR, AND HYDRO OPTIONS

As we've just seen in Chapter 2, energy conservation is one way to reduce fossil fuel consumption. Switching wherever possible to *renewable* energy sources is another. These sources are locally available forms of energy which are continuously renewed by energy transfers from vast external reservoirs of energy. These reservoirs are the sun, the moon's gravity, and the earth's hot internal core.

From the sun we get not only direct solar energy, but also indirect forms such as wind energy, wave energy, hydro power, and biomass energy. The gravitational attraction between earth and moon — together with the earth's rotation — produces ocean tides and tidal energy. The earth's internal heat is the source of geothermal energy.

Fossil fuels, too, are a product of solar energy. Most oil, coal, and natural gas appear to be the fossilized remains of swamps, forests, and sea life that were covered millions of years ago by the earth's shifting crust. On a time scale of million of years, new deposits of fossil fuels may form. But they form at such a slow rate that from our human perspective they are not being renewed.

Extracting Energy from the Wind

Let's begin our look at renewable energy with wind, a form of energy that could eventually be important to us here on Prince Edward Island.

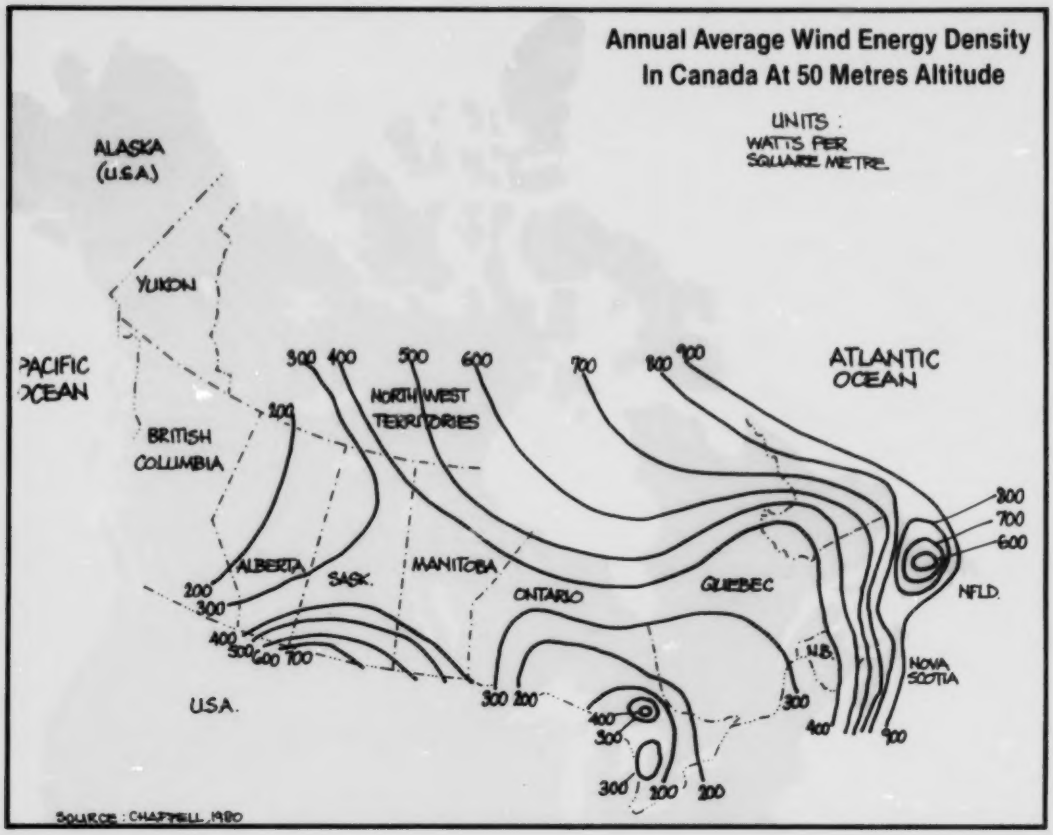
Any moving mass possesses kinetic energy. The amount of energy (E in joules) is determined by the mass (m in kg) and the velocity (v in metres/s) in accord with the equation: $E = \frac{1}{2} mv^2$. Air has mass — a surprising amount of it. The mass of one cubic metre of air at sea level is about 1.2 kilograms. Wind is air in motion, and the wind's energy exists because the air's mass is in motion.

Winds are created by unequal heating of the earth's surface. On a global scale, the sun heats equatorial regions more than polar regions. Hot equatorial air expands and rises, creating areas of low atmospheric pressure. Cool dense air from high pressure regions near the poles then flows along the earth's surface toward these "lows." The solar power reaching the surface of the earth averages about 1.75×10^{17} watts (joules per second). Roughly two per cent of this is transferred to flows of air, and becomes wind power.

Uneven heating also gives rise to local winds. P.E.I. is a land mass surrounded by water. During a summer day, the air above the land gets hotter than the air above the surrounding water. This hot air rises, and cool air moves in from the sea in the form of sea breezes. At night, the air above the land often cools to a lower temperature than the air above the water. This causes the wind to reverse direction.

The overall situation is very complex. Global effects combine with local effects. The earth's rotation modifies wind patterns. So does the unequal heating of the northern and southern hemispheres as the seasons change. The many variables involved make it impossible to predict local wind conditions moment-to-moment. Long-term statistical data is available, however, and that data lets us know the *average* energy content of the winds in a particular area.

The wind power map of Canada shows the average power density of the wind in most regions of the country at a height of 50 metres above the ground. Note that Prince Edward Island winds are more powerful than the winds in many places — about three times the



Prince Edward Island experiences energetic winds.

power of Toronto's winds, for example. The 500, 600, and 700 watt/m² curves pass through the Island. This means that at an altitude of 50 metres, the moving air-mass flowing through a one square metre cross-sectional area has an average power of 500 to 700 watts.

Prince Edward Island has lots of wind, and the wind is free. Unfortunately, the devices needed to extract energy from the wind are relatively costly. These devices go by many names: wind energy collector, wind energy conversion system (WECS), windmill, wind generator, and wind turbine. We'll use several of these terms interchangeably.

Wind turbines come in two general types. Figure 3.1 shows the first: a *horizontal axis wind turbine.* Here a propeller, looking much like an airplane propeller, is kept turned toward the wind. This propeller is usually connected to an electric generator — directly or through gears. In such a system the wind turns the propeller, and in the process, some of the wind's energy is converted into electrical energy.

The second type is the *vertical axis wind turbine.* One of these — a Darrieus rotor model — is shown in Figure 3.2. These machines instantly accept wind from any direction, and their design allows the heavy electrical generator to be mounted near ground level. Also, they tend to cost less than the horizontal axis type. They have one significant disadvantage, however. Although the wind keeps the Darrieus rotor turning once it's in motion, wind will not start the machine from a dead stop. Some external source of energy must be used.

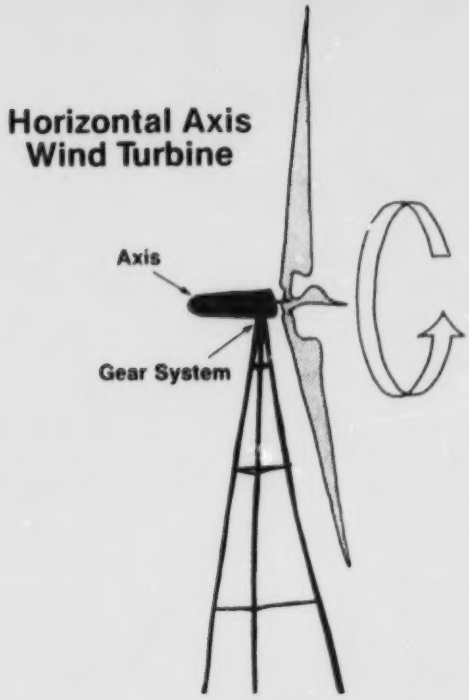


Figure 3.1

Horizontal axis wind turbine must change directions to face the wind.

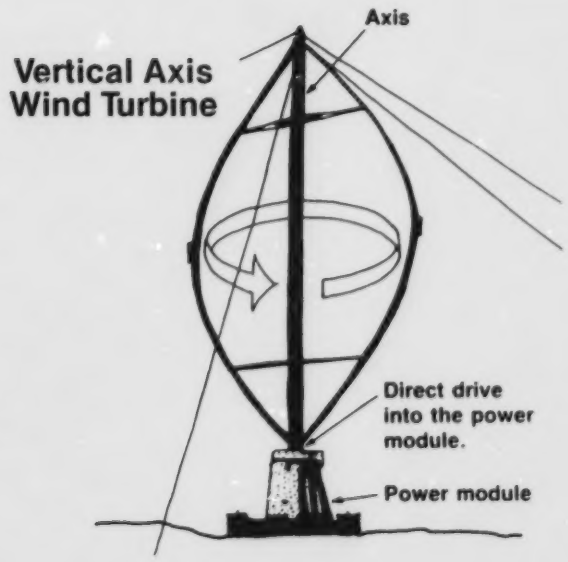


Figure 3.2

The vertical axis wind turbine (VAWT or Darrieus rotor), can use wind from any direction.

Calculating Wind Power

In 1927, Alfred Betz of Göttingen, Germany, derived an equation that shows several interesting things about extracting power from the wind. His equation is:

$P = (0.593)\ \frac{1}{2}\rho\ A\ V^3$

Where:

- P = Power output of an ideal wind system in watts
- ρ = Air density (Typically 1.2 kg/m³)
- A = Area swept by the wind machine's rotor in m²
- V = Wind velocity in meters per second

$P = \frac{1}{2}\rho\ A\ V^3$ is the equation for the power inherent in the wind itself. The factor (0.593) indicates that no wind energy conversion system can hope to collect more than 59.3 per cent of that power. Efficiencies of actual machines are much lower — typically 30 to 45 per cent.

The Greek letter ρ (rho) is the conventional scientific symbol for density. That symbol in the Betz equation shows that the wind's power is proportional to the density of the air. This means that for a given velocity, cold winds have slightly more energy than warm winds, humid winds have more energy than dry winds, and low altitude winds have more energy than high altitude winds. Since differences in air density between one situation and another usually amount to only a few per cent, they are not terribly important.

We see, too, that power output is proportional to the area swept by the wind system's blades — the system's *wind capture area*. In a horizontal-axis system, doubling the length of the propeller quadruples the capture area.

Differences in the wind's *velocity* are seen to have a very great effect on power output. The Betz equation reveals that the power delivered by a wind system varies as the *cube* of the wind velocity. Doubling the wind speed produces eight times as much power output.

Average wind speed values may make wind power look attractive, but there are still those days during the year when the wind hardly blows at all. Wind, unfortunately, is intermittent. There are two things that can be done about this. The first is to use some sort of energy storage scheme. The second is to use the wind to *supplement* other sources of energy.

Small wind generators are often used with lead-acid storage batteries similar to automobile storage batteries. Whenever the wind gets above a certain velocity, the generator delivers energy to the battery. Whenever lights or other appliances are turned on, energy is taken from the battery. If the amount of energy put in, on average, equals or exceeds the amount taken out, and if the storage capacity of the battery is large enough to outlast the duration of the calm periods, electricity will always be available.

Storing Wind Energy

You are now acquainted with electrical *power* — the energy used or produced per second. But there are two other aspects of electricity that we need to become familiar with: *current* and *voltage*.

An electric current is often pictured as the flow of charged particles (electrons) through a wire. The magnitude of the current is related to the number of particles passing a given point each second. Electric current is measured in *amperes*.

Voltage is sometimes called *electromotive force*, or *EMF*, and it is a bit like force in the mechanical sense. Voltage is the pushing/pulling quality that gets those particles of electricity (electrons) flowing through the wire. It is measured in *volts*.

The amount of work done by an electric current depends on both the size of the flow (amperes, A) and the size of the push/pull (voltage, V).

Conveniently, electrical power (P in watts) equals simply the current (I in amperes) times the voltage (V in volts):

Power = Current times Voltage

$$P = IV$$

Q: How much current does a 60-watt bulb draw if operated at its rated voltage of 120 volts?

A: $I = P/V$

$I = 60\ W/120\ V = 0.5\ A$

The work done or energy supplied (E in watt-seconds, watt-hours, or kilowatt-hours) equals the power (P in watts or kilowatts) times the time (t in seconds or hours):

Energy = Power times Time

$$E = Pt$$

Q: How much energy does a 60-watt bulb consume in 8 hours of operation?

A: $E = Pt$

$E = 60\ W \times 8\ h = 480\ Wh = 0.48\ kWh$

Problems to Solve:

Imagine that you have bought a small wind generator for your cottage at the shore. It is designed to charge a 12-volt battery. When the wind reaches 14 km/h the device starts charging. At 21 km/h it produces 250 watts. And when the wind velocity is 35 km/h or greater, the generator produces its full rated output of 1000 watts.

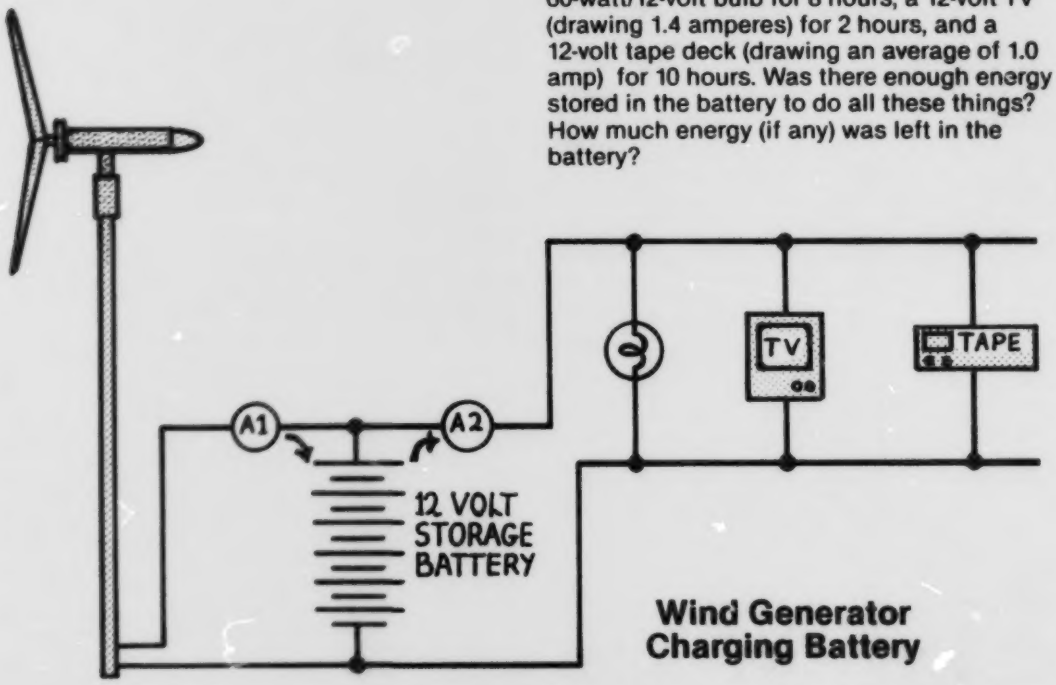
You have hooked up the wind generator as shown in the diagram below. A1 is an ammeter that measures the battery charging current. A2 is another ammeter. It measures the battery discharge current. Assume that the battery voltage is 12 volts at all times, and that the battery's rated capacity is 1000 ampere-hours.

Using the above information, solve the following problems:

1. Calculate the charging current you would expect to get at the following wind speeds:
   a. 12 km/h
   b. 21 km/h
   c. 35 km/h

2. For the first 10 hours of operation you looked at the charging ammeter frequently. There was a steady wind blowing, and you estimate that the current averaged 30 amperes during that period. Assuming that the battery is 100 per cent efficient, and your estimate of the average charging current is correct, how much energy was stored in the battery at the end of that 10 hours? What percentage of the maximum energy storage capacity of the battery does that represent?

3. At the end of the 10 hour period the wind died down and didn't pick up again for the next 30 hours. During that 30 hours you ran a 60-watt/12-volt bulb for 8 hours, a 12-volt TV (drawing 1.4 amperes) for 2 hours, and a 12-volt tape deck (drawing an average of 1.0 amp) for 10 hours. Was there enough energy stored in the battery to do all these things? How much energy (if any) was left in the battery?

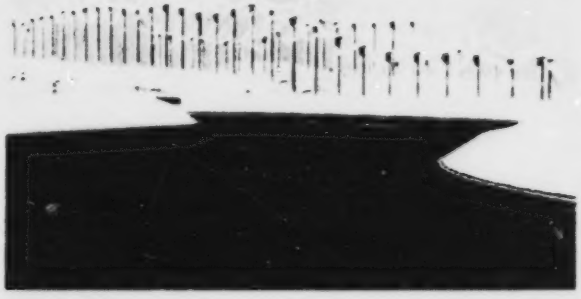


Wind Generator Charging Battery

Energy Storage

Storage batteries are quite expensive and have limited storage capacity, so storing energy in batteries is feasible only for small systems. Several large-scale energy storage schemes have been proposed, but none have yet been developed to the point where they are economical. In one proposed scheme, heavy rotating flywheels would store the excess energy as kinetic energy. In another, electricity from the wind generator would be used to convert water into hydrogen and oxygen. These elements would then be recombined in a *fuel cell* to produce electricity. In a third scheme, some of the wind-generated electricity would be used to pump water into a high reservoir. Then, during calm periods, the water would descend from the reservoir and pass through a turbine to generate electricity.

Using the wind, not as the sole source, but as a *supplementary* source of electricity is the most practical use of large-scale wind energy today. It's practical because no expensive energy storage is required. In some windy locations whole arrays of wind turbines have been installed. These multiple installations are called *wind farms,* and the electricity the turbines generate is fed directly into the electrical distribution network. Thus, whenever the wind is blowing, some of the electricity delivered to customers is wind-generated electricity. When the wind is not blowing, customers continue to get electricity — but electricity generated by other means.



This wind farm in a California mountain pass feeds electrical energy into the power grid. Will such installations make sense here some day?

Technological Maturity

People go through different stages of growth and development, and technologies do too. We refer to some technologies as being in their infancy, and to others as being mature. The telephone is a mature technology, for example. So are bicycles, toasters, and washing machines. In mature technologies a few "best" designs have sifted out from a great many initial trials. These are the designs that have proven over time to be both economical and reliable.

The technology of wind-generated electricity has not yet reached maturity. This technology is beyond its infancy, but there is still much development work to be done. There are wind turbines that work well in California wind farms, where the wind coming through mountain passes is steady and there is no ice. But these same turbines are not necessarily suited to our gusty winds and harsh winter weather.

The Atlantic Wind Test Site at North Cape, P.E.I., is a research facility operated by the Institute of Man and Resources. It is there to help the wind turbine industry mature. Wind turbines are tested at North Cape under conditions that include freezing rain, ice fog, snow, high winds, and temperatures that go down to -30°C. Through efforts like this, the reliability of wind conversion equipment is gradually going up and the cost is coming down.

In 1988 the cost of generating electricity with large wind turbines at good sites had dropped to as little as $0.10 to $0.15 per kWh. At that time, however, the Island's utility could buy electricity for about $0.05 per kWh from New Brunswick, and wasn't interested in purchasing power at higher rates.

Assuming that wind turbine costs continue to drop, the day may well come when we have wind farms here on P.E.I. Our wind levels are high enough to be interesting, and our strongest winds occur in the winter when electrical demand is highest. It makes sense to watch developments in this area. We may not be too far from the day when wind turbine reliability and cost are acceptable.

The Atlantic Wind Test Site at North Cape, P.E.I., is a research facility operated by the Institute of Man and Resources. Wind turbines are tested under conditions that include freezing rain, ice fog, snow, high winds, and temperatures that go down to -30°C.

OPTIONAL PROBLEMS:

1. The average wind velocity at the Charlottetown Airport is 19.3 km per hour. Use the Betz equation to calculate the power output of an ideal system having a capture area of 10 square metres when the wind velocity is 19.3 km/h.

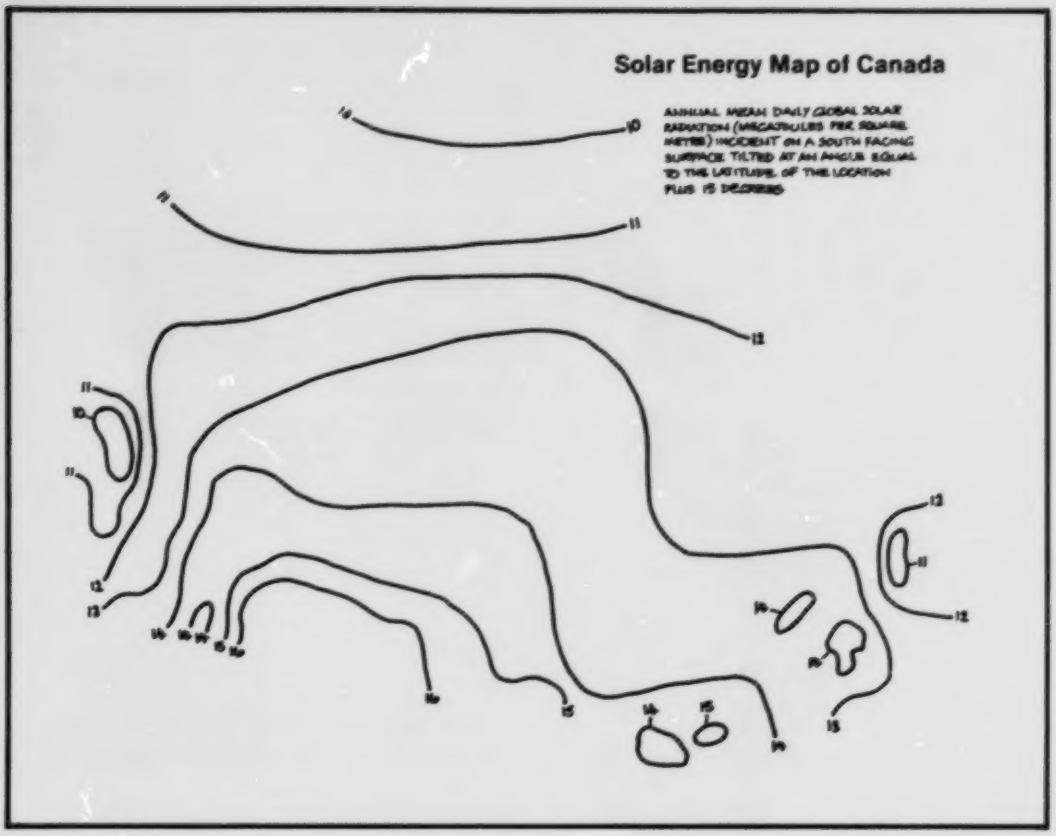
2. Air seems weightless to us. Does each cubic metre of air really have a mass of 1.2 kg? Design an experiment to find out.

Direct Solar Energy

Most people associate solar energy with tropical and subtropical areas, not Canada. But there is considerable potential here, too, for using direct solar energy.

The solar energy map of Canada makes it clear that the solar energy level on P.E.I. is significant. Island solar collectors, when mounted at an angle of 60 degrees from the horizontal and facing south, receive an average daily energy input of 13 to 14 megajoules per square metre of collector surface. The energy level is higher in the summer than in the winter, of course, but even in winter it's substantial. In Summerside, for example, the December daily average is 8.7 MJ/m^2; that's 53 per cent of the July average which is 16.5. The incident power—averaged over 24 hours—is 100 $watts/m^2$ on a December day and 190 $watts/m^2$ on a July day.

The direct solar-energy conversion systems in use today convert radiant solar energy either into heat, or into electricity. Flat-plate solar collectors use sunshine to raise the temperature of water or air. The heated liquid or gas is then used for some purpose such as heating a building, heating hot water, or heating a swimming pool. The other type of solar panel, the photovoltaic type, uses silicon solar cells to generate electricity. These cells were developed as part of the space program, and produce a steady electrical output when illuminated by the sun.


Solar Energy Map of Canada
ANNUAL MEAN DAILY GLOBAL SOLAR RADIATION (MEGAJOULES PER SQUARE METRE) INCIDENT ON A SOUTH FACING SURFACE TILTED AT AN ANGLE EQUAL TO THE LATITUDE OF THE LOCATION PLUS 15 DEGREES

Prince Edward Island has a significantly higher solar energy level than many places in Canada.

Calculating Incident Solar Power

The solar energy map of Canada gives the mean daily energy that is captured by a south-facing reflector tilted at an angle to the horizontal equal to 15 degrees plus the latitude of the location. From this incident energy data it is possible to calculate the average incident power by using the equation $P = E/t$.

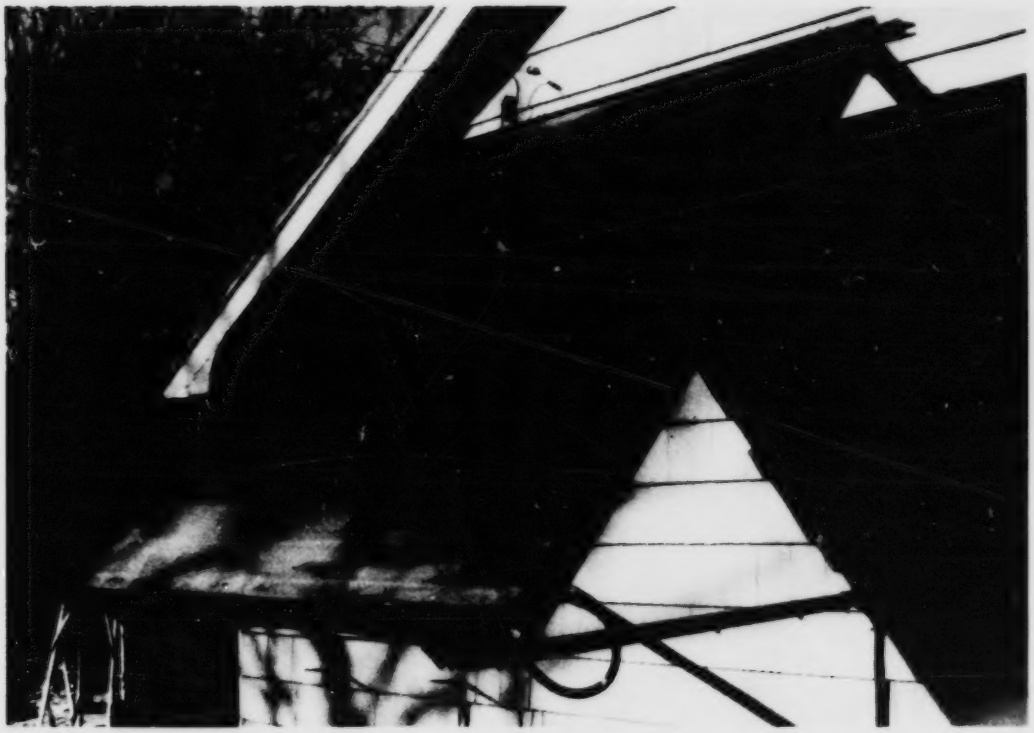
If, for example, the incident radiation during a 24 hour period is 16.5 MJ/m², the average daily incident power during that 24 hours would be:

$P = E/t$

$= 16.5\ MJ/m^2 / 24\ h$

$= 1.65 \times 10^7\ Ws/m^2 / 2.4 \times 10^1\ h \times 10^3\ s/h$

$= 1.9 \times 10^2\ W/m^2$



So far, the main use of solar energy on P.E.I. has been to heat domestic hot water—hot water for bathing, clothes washing, dish washing, etc. On a yearly basis, a typical system supplies about half the hot water used by a family of five.

EXPERIMENT

Estimating the Sun's Power Output

Hypothesis: The sun's radiant power output can be estimated by comparing it with the output of a 200-watt light bulb, and applying the inverse-square law.

Materials: silicon solar cell, milliammeter, metric ruler, clear-glass 200-watt bulb and wired socket—no lamp shade or reflector.

Background information: The average distance between the sun and the earth is 148 800 000 km. Also, incident radiant power is inversely proportional to the square of the distance from the source. This can be expressed in an equation:

$p = k \times P / d^2$

Where:

p = incident radiant power
P = radiant power output of the source
d = distance between source and point of incidence
k = a constant associated with the uniformity of radiation

Q: What is the effect on incident power if the distance to the source is doubled?

A: Let:
p_1 = the initial incident power
d_1 = the initial distance
p_2 = the final incident power
d_2 = the final distance

Rewriting our equation:
$p_1 d_1^2 = kPv$

But, $p_2 d_2^2$ also equals kP. And since k and P remain the same:
$p_1 d_1^2 = p_2 d_2^2$

If the distance is doubled, $d_2 = 2d_1$

Solving for p_2:
$p_2 = p_1 d_1^2 / d_2^2$
$= p_1 d_1^2 / (2d_1)^2$
$= p_1 / 4$

Thus, the incident power will be only ¼ of what it was before the distance was doubled.

Procedure: Connect the solar cell to the milliammeter as shown below.

If, when the cell is illuminated, the meter needle moves down scale rather than up scale, reverse the connections to the meter.

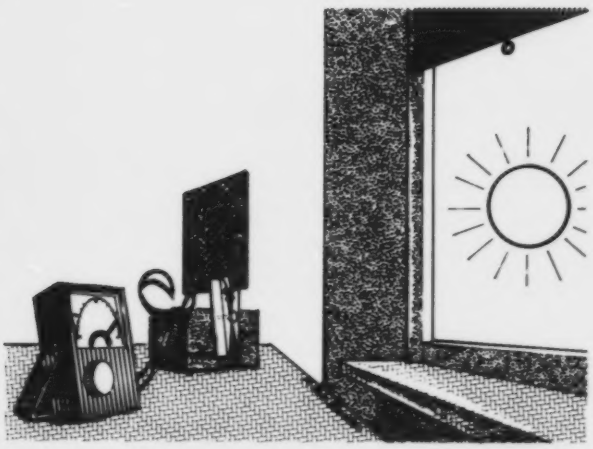
Put the cell in direct sunlight and orient the cell to produce the maximum possible reading on the meter. (This should occur when a straight line from the cell to the sun is at right angles to the plane of the cell.) Record the meter reading.

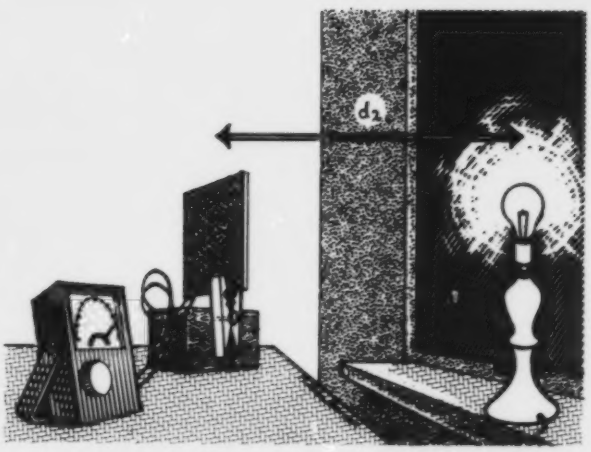
Repeat the above procedure using the 200-watt light bulb as an energy source instead of the sun. Orient the cell for maximum reading on the meter, and adjust the distance between the solar cell and the bulb until the reading is the same as it was with the sun as the source. Measure the distance from the solar cell to the bulb's filament.

Calculations and Conclusions

1. Using your experimental data, calculate the power output of the sun.

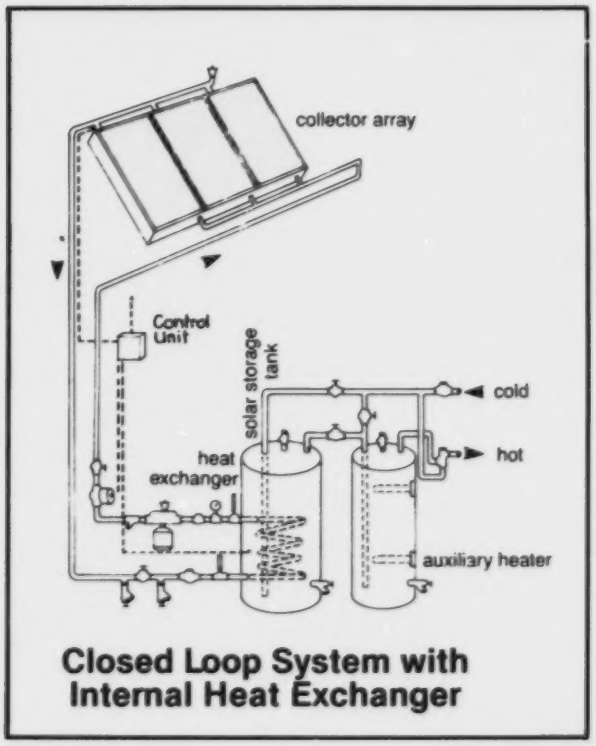
2. How does your estimate compare with the accepted figure for the sun's power output: 3.9×10^{26} watts? What factors might account for the difference? How many 200-watt light bulbs would it take to equal the power output of the sun?





So far, the main use of solar energy on P.E.I. has been to heat domestic hot water — hot water for bathing, clothes washing, dish washing, etc. During the mid-1980s the federal government had a program that provided financial assistance to those who wanted to install solar hot water systems. Interestingly, far more systems, per capita, were installed here than in any other province.

The usual solar hot water system involves a flat-plate solar collector and an insulated hot water storage tank. The typical collector consists of a shallow rectangular box containing a flat black plate to which tubing has been attached. The box is topped by a sheet of glass or transparent plastic. The sun shines through this "window," and much of the radiant energy is absorbed by the black plate and becomes heat energy. The transparent lid traps the heat inside the collector box, and the plate gets hot.



A solar hot water system — one common design.

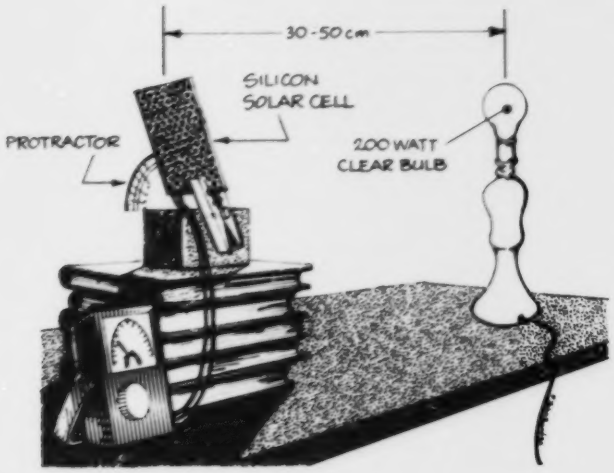
Liquid circulates through the collector plate tubing, and this liquid carries the heat to the hot water storage tank. In many "drain down" or "drain back" systems this liquid is the domestic hot water itself. These systems are designed to drain water out of the collector when it's not in actual use. This is done to prevent damage to the collector should the temperature be low enough to freeze the water. "Closed loop" systems circulate an anti-freeze solution through the collector, and transfer the heat from this liquid to the domestic hot water in a heat exchanger. The collectors used in these systems range from 20 to 73 per cent efficient in converting radiant solar energy to heat energy. The actual figure depends both on collector design and operating conditions. In a typical P.E.I. solar hot water installation, two 3.0 m^2 collectors provide 50 per cent of the hot water used during a year by a family of five. Such a family typically uses 300 litres of hot water per day. During the summer, all of its is heated by the sun; in the middle of winter, very little of it is.

EXPERIMENT

Solar Panel Output and Angle of Incident Radiation

Hypothesis: The output of a flat solar collector depends on the angle at which the radiant energy strikes it.

Materials: silicon solar cell, milliammeter, protractor, books or other supports, clear-glass 200-watt bulb and wired socket — no lamp shade or reflector.



Procedure: Pile up books until the solar cell is the same height above the table top as the bulb filament, and 30 to 50 cm from it. Connect the solar cell to the milliammeter. Turn out any room lights. Turn the lamp on, and select a milliammeter range that gives a half-scale reading or higher. (Adjust the filament-to-cell distance if necessary.) Now, keeping the filament-to-cell distance constant, change the cell angle. Take meter readings at angles of 0°, 30°, 45°, 60°, and 90° with the vertical.

Calculation and Conclusions

On graph paper, plot your milliammeter readings on the y-axis, and the angle on the x-axis. What orientation gives maximum current?

Discuss with the class the pros and cons of various solar panel orientations in real-world situations. Consider both the compass direction, and the angle with respect to the horizontal.

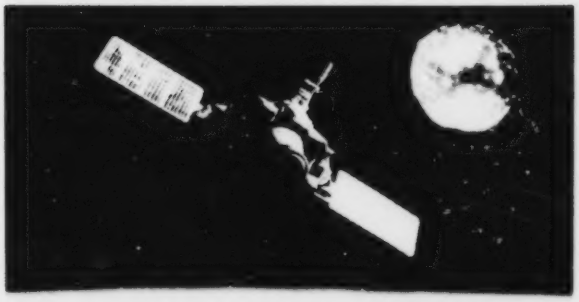
One economically attractive use for solar energy on P.E.I. is swimming pool heating. Solar collectors for heating domestic hot water must be glazed, all-weather units, and are therefore fairly expensive. Outdoor swimming pools, on the other hand, are used only in the summer. Since there is no danger of freezing, much less expensive collectors are practical. In the simplest systems, black plastic pipe or hose is simply coiled up on a roof. Then, during the daylight hours, the swimming pool water is circulated through it. Inexpensive, unglazed flat plastic collectors also work well for pool heating.

The most practical use of solar energy today — the use that makes most economic sense — is converting solar energy to low-temperature heat energy. That other use — converting solar energy directly into electricity — is one with gradually improving economics. Today, however, these devices still have several drawbacks:

- Silicon solar cells have low efficiency.
- Silicon solar cells are expensive.
- In most situations, silicon solar cells must be used jointly with expensive energy storage devices.

Silicon solar cells of the type developed to power satellites convert only 12 to 14 per cent of the solar energy that strikes them into electrical energy. The individual cells are costly, and because the voltage and current output of each cell is limited, photovoltaic solar panels are made up of many interconnected cells. In normal use, the panel delivers energy *to* a storage battery during daylight hours. Energy is then taken *from* the battery as needed.

Silicon solar panels, even in the late 1980s, still cost many dollars per watt of electrical output. As a result, meeting all of a normal household's electrical needs this way has been impossibly expensive. Fortunately, some critical uses of electrical energy — the electronic uses — don't require much power. A 35-cm diagonal (14-inch) black and white TV, for example, draws only 14 watts (joules per second) Because of this, it might make sense (even at a high price per watt) to install a solar panel at a remote cottage — mainly to power electronic equipment.



Silicon photovoltaic solar cells were initially developed to power satellites.

Small-Scale Hydro Possibilities

When radiant solar energy warms the surface of the earth, water evaporates. As the sun's energy warms oceans, lakes, and the soil, the random movement of their water molecules increases. As a result, some of the molecules break away from the liquid water and enter the atmosphere. Some of this sun-warmed *water vapour* rises high into the atmosphere. As it rises, it cools. And when it cools sufficiently, it condenses into clouds — and into rain, snow, and other forms of precipitation.

Precipitation brings liquid water back to the earth. The water that happens to fall on high ground has both height and mass — and therefore potential energy. This water descends slowly toward the sea in creeks, streams and rivers. As it descends, its original store of potential energy gradually diminishes.

The idea behind hydro or water power is to convert some of water's potential energy into active forms of energy — forms that are useful to people. This conversion is most efficiently done at sites where the water level drops abruptly. Nature has created a few of these places — Niagara Falls, for example. Others are created artificially by damming rivers.

Large hydroelectric projects require major rivers — rivers which drain an extensive land area. They also need favorable dam sites — sites which, when dammed, create a large difference in water level. Prince Edward Island has no rivers like this. Most of our wide "rivers" are actually inlets of the sea — tidal estuaries — not true rivers. Our real rivers are all small ones. Despite this, small-scale water power flourished here for many years.

In the early 1800s many streams and rivers were dammed to provide the mechanical power needed to grind grain, saw timber, make shingles, and card wool. In the late 1800s these mills began to be converted into small electric generating plants. Kenneth Bell, in his book on the history of electricity on P.E.I., estimates that 15 small mills were converted to electrical generation between 1885 and the early 1920s [1]. This was usually done by connecting the existing water wheel or turbine to an electric generator by means of belts and pulleys.

[1] *Check with the Prince Edward Island Museum and Heritage Foundation for information on the availability of Mr. Bell's book.*

Because electric lighting was then the only household use for electricity, these first generators ran only at night. Later, when electric washing machines came along, some of these small electric utility companies also operated during the day on Mondays. And when radio became popular, the company in Crapaud turned its generator on from noon to 1:00 p.m. so that customers could listen to the news.

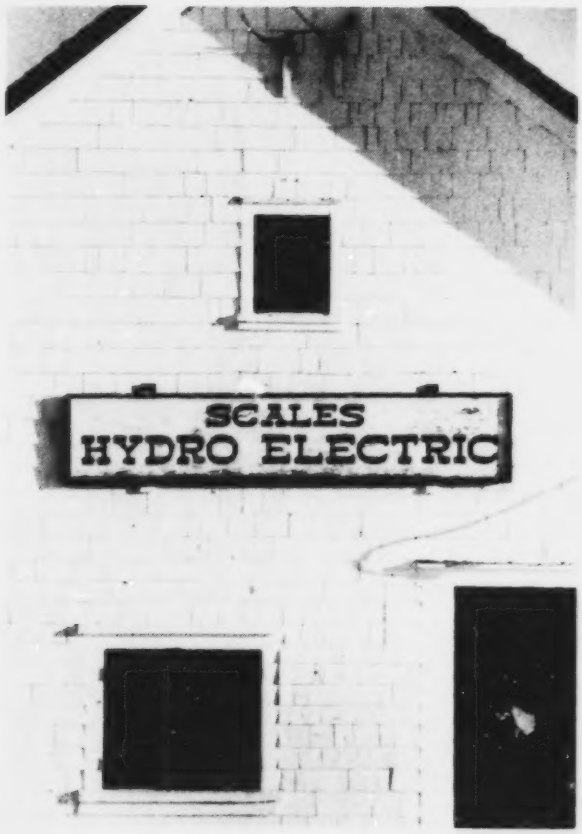
These early water-power systems were dotted all over the Island. The Montrose River near Alberton was dammed in 1850 to power a saw mill. This mill was converted into a grist mill in 1852, and converted again in 1914 — this time into a hydroelectric plant for the town of Alberton.

At one time there were seven dams on the Dunk River. One of these was at Breadalbane. It powered a sawmill in the early days, and produced electricity for the community from 1917 to 1952.

The largest, and longest surviving, hydroelectric plant was also on the Dunk River — at what is now known as Scales Pond. It was built by the Dunk River Hydroelectric Company in 1926, and boasted a large 100-kilowatt generator. The plant changed hands a couple of times, but continued to produce hydroelectricity until 1965 when it was bought by Maritime Electric Company.

The largest hydroelectric system at the eastern end of the Island was the one built on the Montague River in 1899. It was operated by the Montague Hydroelectric Company until 1933 when the dam collapsed.

Electric utility companies saw a need for daytime operations when electric washing machines replaced these traditional ways of washing clothes.



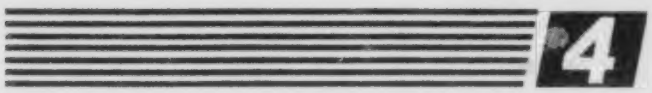
The largest, and longest surviving, hydroelectric plant on P.E.I. was on the Dunk River at what is now known as Scales Pond. It was built by the Dunk River Hydroelectric Company in 1926, and boasted a 'large' 100-kw generator.

Unfortunately, figures aren't available on the generating capacity of many of these small hydroelectric systems. It seems likely, however, that the total generating capacity of all of them put together was well under one megawatt. A recent estimate of our hydro capacity based on rainfall figures is also "less than one megawatt." When we compare that figure with the Island's 1986 peak electrical demand of 113 megawatts, it seems clear that we can't expect hydroelectricity to solve our current electrical energy problem.

Furthermore, like other energy options, hydro also has its negative side. Dams sometimes interfere with natural processes like fish spawning. They sometimes flood wildlife habitat, or good agricultural land. Poorly designed or poorly maintained dams have been known to collapse. And silt gradually builds up behind dams. Nevertheless, water power is a resource that will remain with us. There are many small rivers on P.E.I., and at some time in our future there may once again be a significant — if selective — role for micro-hydro systems.

The present-day Scales pond installation.

CHAPTER

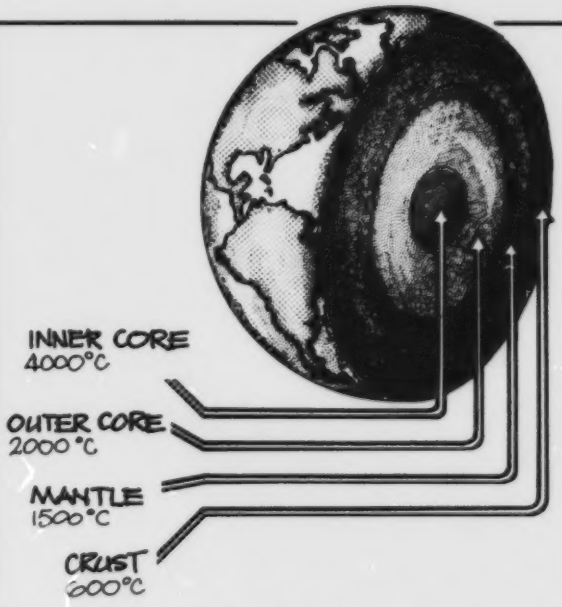


GEOTHERMAL AND NUCLEAR OPTIONS

Geothermal Energy and Heat Pumps

How hot is the earth? That depends very much on where you are on the globe, and how far beneath the surface you go. On Prince Edward Island, as in most places, the temperature of the top few inches of soil goes up and down with the seasons. It's not exactly the same as the air temperature, but it's not too different either. If we go down 50 metres or so, the temperature is almost constant, regardless of the season. On P.E.I. this value is often about 7°C—slightly higher than the average year-round outside air temperature of 5° or 6°C.

If we go deeper than this, the temperature begins to rise. The geologists' term *thermal gradient* refers to the number of degrees C the temperature rises for each kilometre of depth. For test wells drilled on P.E.I. this value has ranged from 15 to 26°C/km, with 16 and 17°C/km being the most common values encountered. The deeper one goes, the hotter it gets. At a depth of 50 to 100 km the temperature would reach 1200°C—the melting point of rock. And at the very center of the earth the temperature is estimated to be 4000°C. This heating of the inner earth is attributed to the slow decay of radioactive materials over very long periods of time.



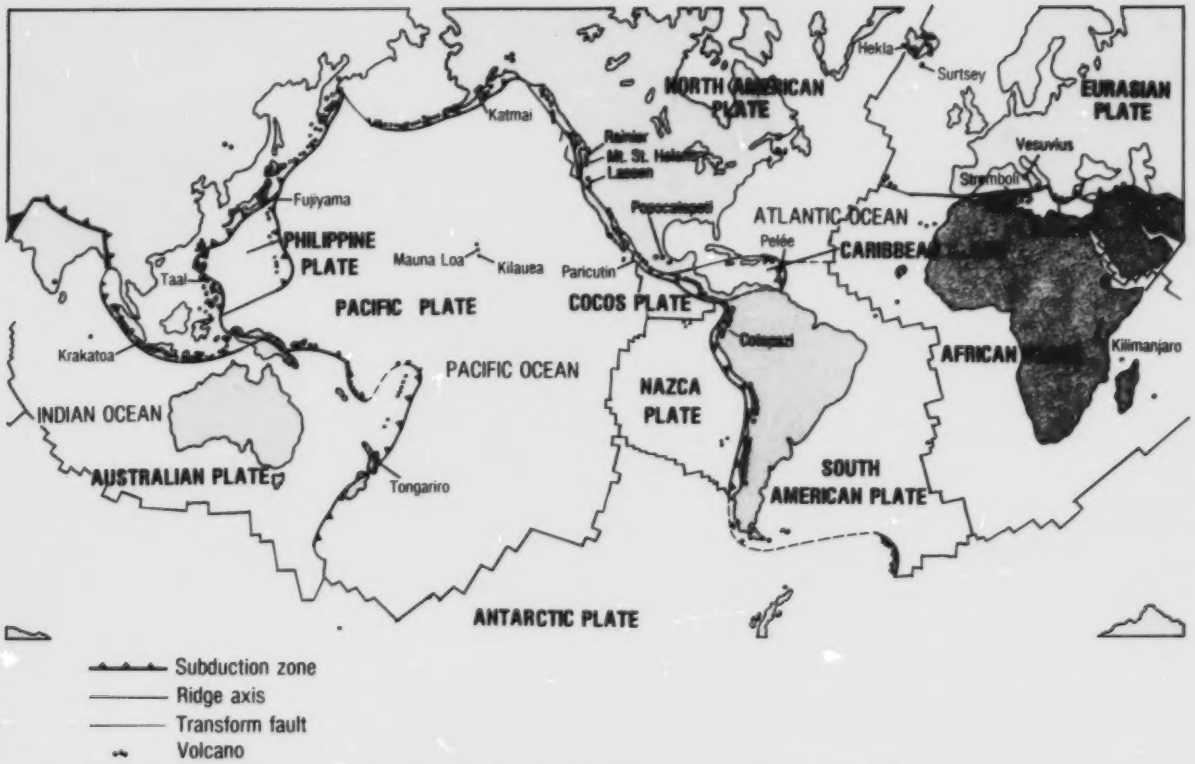
Cross Section of the Earth

Figure 4.1

The average thickness of the earth's solid crust is about 50 km, but it's not that thick everywhere. The crust consists of continent-sized "tectonic plates" which float on a viscous layer beneath, and slowly shift position—perhaps 10 cm per year. (See Figure 4.2.) The colliding of these plates is a major cause of earthquakes. It is also at plate boundaries where the crust

is thinnest. In some places it is so thin that we have active volcanos, and molten rock (lava) oozes up to the surface.

In other places near plate boundaries (hundreds of them in Western Canada) the subsurface rock is merely hot. Groundwater which passes over these hot rocks becomes warm water, hot water, or steam. Hot springs, geysers, warm water reservoirs, and steam reservoirs are some of the possible results. In those rare situations where steam reservoirs exist, electricity can be generated. This is being done in Italy, New Zealand, and California. In the more common situation where the water is just hot or warm, it can be used to heat buildings. This is done on a large scale in Reykjavik, the capital of Iceland.



Source: From EARTH, Second Edition, by Frank Press and Raymond Siever. W.H. Freeman and Company. Copyright © 1978

Tectonic Plates

Figure 4.2

It is near tectonic plate boundaries that the earth's crust is the thinnest, and geothermal activity is the greatest.

Geothermal Heating and Cooling on P.E.I.

Those P.E.I. test-well thermal gradients in the 15 to 26°C/km range indicate that it would be necessary to go down several kilometres to reach temperatures above the boiling point of water. This is too deep for practical geothermal energy systems.

As we've seen, what P.E.I. does have near the surface are cooler-than-summer, warmer-than-winter temperatures in the 5 to 10°C range. At first glance, water or earth at these temperatures might seem to have no energy value, but that is not the case. The geothermal temperatures we do have are ideal for certain purposes. Take potato storage, for example. To store potatoes over the winter you must keep them from freezing. To extend their dormant period and keep them from sprouting you must keep them cool. Ideal potato storage temperatures range from 3°C to 10°C, depending on whether the potatoes are to be used for seed, table, or processing.

The modern way to store potatoes is to build a large insulated building, then use oil and electrical energy to keep the potatoes at a constant temperature. The building must be heated in the winter. It must be cooled in the spring and summer. And the large piles of potatoes must be ventilated with electric fans and blowers to keep the temperature inside the pile from rising. This method of storing potatoes uses lots of energy.

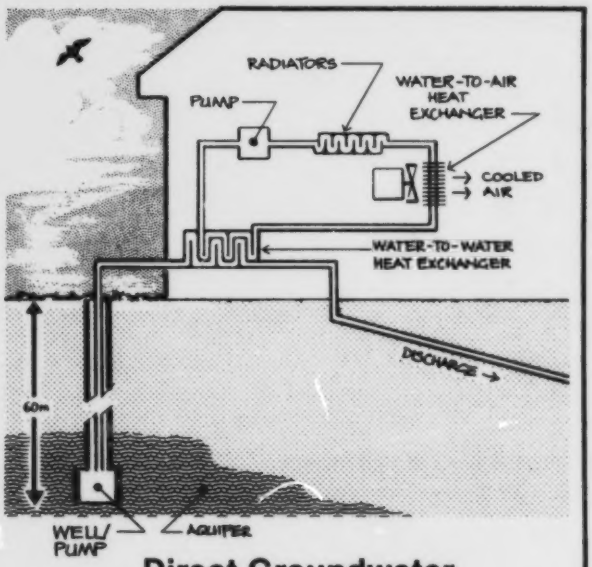
Our ancestors had no modern technology, yet they came up with a workable low-energy way of storing their potatoes. They built half-buried storage barns and underground "cold rooms." These provided acceptable storage—and in some cases nearly ideal storage. The available geothermal environment was put to good use, and other energy sources weren't needed.

Low-energy air conditioning is another interesting use of P.E.I.'s geothermal reality. The usual way to cool or "air condition" a building in summer is with electrically operated refrigeration equipment. It works, but the equipment is expensive to buy and expensive to run.

Several buildings in Charlottetown—including the courthouse, the Brecken-Yates building in the Harbourside complex, and MacLaughlan's Motel—are cooled by another method. At each location a well was drilled to a depth of about 60 metres. At this depth water was found in quantity—quite salty water in the wells near the harbour. The temperature of the water from all three wells is about 10°C.

In these groundwater cooling systems, water pumped from the well passes through a flat-plate heat exchanger where it cools the building's "heating system" water to about 11°C. This 11° water circulates through radiators and ventilation heat exchangers, cooling the building.

In the process of cooling the building water, the well water acquires heat, and this warmed well water is discharged through a storm sewer to the harbour—as shown in Figure 4.3.



Direct Groundwater Cooling System

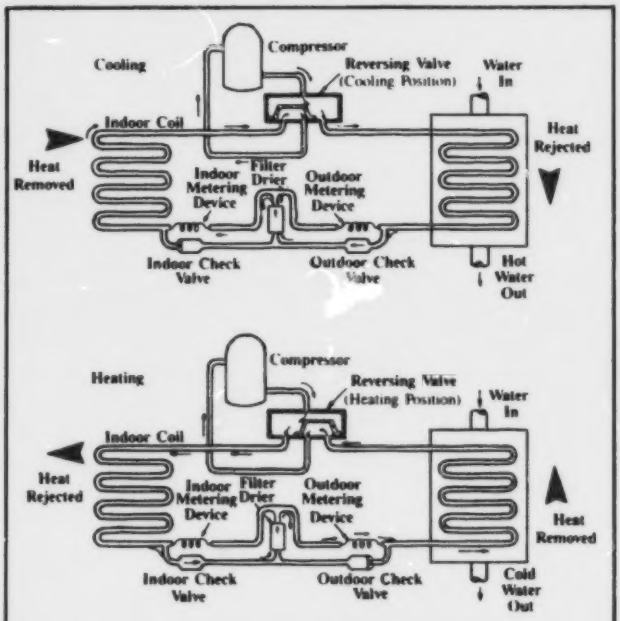
Figure 4.3

Water pumped from the well passes through a flat-plate heat exchanger where it cools the building's 'heating system' water to about 11°C. This 11°C water circulates through the radiators and ventilation heat exchangers, cooling the building.

Water-to-Air Heat Pumps

The heating and cooling system at the Prince Edward Hotel uses a groundwater heat pump. Here, too, a brackish well was drilled. But the water from this well is not used for direct cooling. Instead, it is used in conjunction with a *heat pump* to cut the energy cost of both heating and cooling the hotel. (See Figure 4.4.)

In summer, heat is pumped from the hotel interior, and the well water cools the heat pump's condenser. In winter, heat is pumped from the 10°C well water into the hotel. The heat pump requires external energy, but much less than it would if the well water did not provide a source of heat in winter and a "sink" for excess heat in summer.



Water-to-Air Heat Pump System

Figure 4.4

A heat pump is a type of compression refrigeration equipment used for heating, or for heating and cooling. In its heating mode, a heat pump transfers heat from a low temperature heat source to a higher temperature heat sink.

Heat Pump Efficiency

A heat pump is a type of compression refrigeration equipment used for heating, or for heating and cooling. In its heating mode, a heat pump transfers heat from a low temperature heat source to a higher temperature heat sink.

All refrigeration equipment pumps heat. A refrigerator pumps heat from the food within to the room without. (You may have noticed that the coils on the back of your refrigerator get hot when its compressor is running.) An air conditioner pumps heat from the air inside a building to the air outside. (You may also have noticed the hot air coming from an air conditioner's outdoor condenser.)

If we turned a room air conditioner around, we could use it as a heating device. It would then extract heat from the outside air and deliver it to the inside space. Unfortunately, this arrangement would have poor efficiency on cold winter days. We can see this more clearly by coming to understand the concept of **Coefficient of Performance.**

The coefficient of performance (COP) of a heat pump is a measure of its energy efficiency. The COP is the ratio of heat energy output to the compressor work input. The ideal COP (which neglects compressor and motor losses) can be calculated from the heat pump's input and output temperatures:

$$\text{COP (Heat Pump)} = \frac{T_H}{T_H - T_L}$$

Where:

T_H = Temperature of the heating or output side (K)

T_L = Temperature of the cooling or input side (K)

(Temperature in Kelvins = °C + 273.15)

Let's assume that in the equation above T_H equals 80°C and the outside air temperature (T_L) equals -20°C.

$$\text{COP} = \frac{353}{353 - 253} = \frac{353}{100} = 3.53$$

Now imagine that instead of trying to pump heat from -20°C air, we pump heat from 10°C water. The COP of this more efficient arrangement is:

$$\text{COP} = \frac{353}{353 - 283} = \frac{353}{70} = 5.04$$

In the first example, the heat pump delivers 3.53 times the compressor work input. In the second, it delivers 5.04 times. Looking at it another way, the energy needed to deliver a given amount of heat to the building interior in the second example is only 70 per cent of that required in the first.

QUESTION

If a heat pump can deliver a heat-energy output that's 3 to 5 times greater than the mechanical energy input, isn't it creating new energy? And doesn't this contradict the first law of thermodynamics?

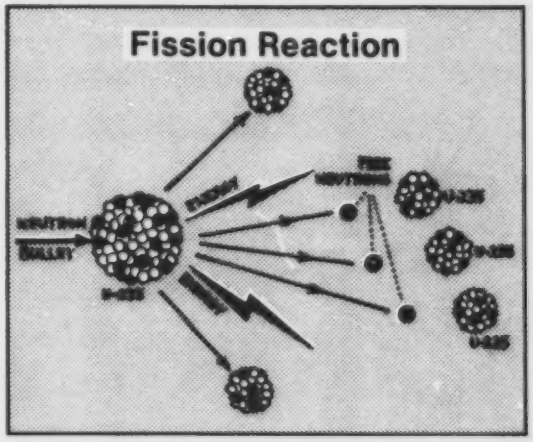
The Nuclear Option

Einstein's theory of relativity implies that matter and energy are merely two different forms of the same physical reality. Each can, under very special circumstances, be converted into the other.

Uranium Fission

One set of special circumstances involves the heavy metal uranium. Refined natural uranium contains two kinds of uranium atoms—two *isotopes* of uranium. Nearly all—99.3 per cent—of natural uranium is U-238; 0.7 per cent is U-235. Surrounding the nucleus of all uranium isotopes is a cloud of 92 electrons. And within the nucleus of all uranium isotopes are 92 protons. The difference between isotopes lies in the number of neutrons: 146 in a U-238 nucleus; 143 in U-235.

When the nucleus of a U-235 atom is struck by a slow-moving neutron, fission takes place. The atom splits apart into two atoms of lesser mass. There are about 40 possible pairs of isotopes that can be produced. The most common combinations involve isotopes having nuclear masses of 95 and 139—and most are unstable *radioactive* isotopes. Fast-moving neutrons are also released in this process. The total mass of the fission products is always slightly less than the mass of the original U-235 atom. The small difference represents mass that has been converted to energy.



When the nucleus of a U-235 atom is struck by a slow-moving neutron, fission takes place. The atom splits apart into two atoms of lesser mass, and energy plus free neutrons are released.

Nuclear Power

Those extra neutrons released when U-235 is fissioned play a key role in the practical production of nuclear power. In an atomic bomb, the extra neutrons released when one atom is split immediately split other atoms which release more neutrons, etc. A chain reaction occurs, and in a matter of microseconds a small amount of U-235 is converted to a large amount of energy.

In a nuclear reactor of the type used to produce continuous energy, the percentage of fissionable material—U-235 and plutonium—is much less than in an atomic bomb. And extensive precautions are taken to see that an uncontrolled chain reaction does not occur. Nuclear power plants are designed to allow the fission process to happen in a self-sustaining but controlled way. This is done primarily by controlling the number and velocity of the free neutrons within the reactor. *Moderators* such as water (particularly heavy water), graphite, and beryllium are used to speed the reaction up. They do this by slowing neutrons down, increasing the likelihood that they will split U-235 nuclei. (Fast moving neutrons tend to bounce off these nuclei; slow neutrons are better able to penetrate them and produce fission.) *Control* substances such as cadmium, silver, stainless steel, and boron absorb excess neutrons and are used to slow the reaction down.

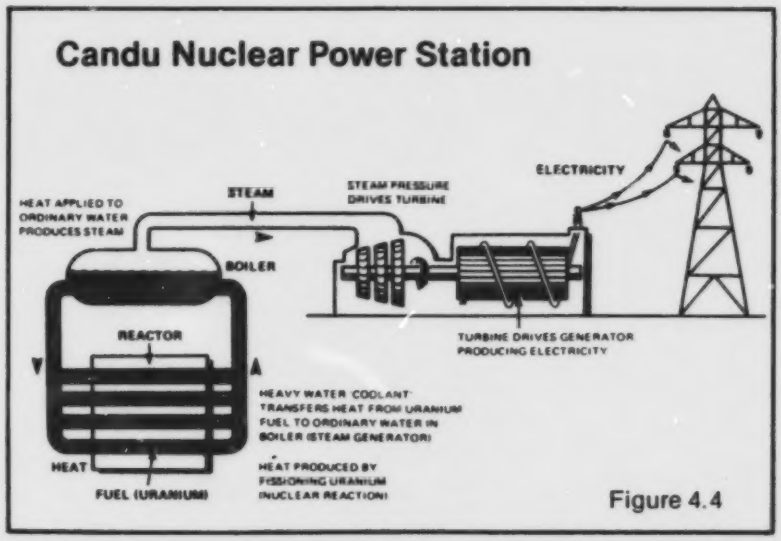
The electricity-generating reactors used in Canada are of the CANDU type. CANDU is an acronym derived from **CA**Nada-**D**euterium-**U**ranium. This type of reactor uses natural uranium as its fuel. It uses heavy water (deuterium oxide) as a neutron-slowing moderator. And it uses stainless steel rods, cadmium rods, plain water, and the rare-earth element gadolinium to absorb free neutrons and provide control.

The major components of a CANDU power station are shown in Figure 4.4. Pressurized heavy water is heated by the nuclear fission going on in the reactor core. This heat is transferred to ordinary water in a boiler, where the heat turns the water to steam. Steam from the boiler then passes through turbines which generate electricity.

The reactor part of the system is shown in more detail in Figure 4.5. The reactor vessel is a large, stainless steel tank called a calandria. It is penetrated by several hundred horizontal tubes. Inserted into each of these calandria tubes is another tube—a pressure tube containing the nuclear fuel bundles. Each bundle consists of several hollow tubes of zirconium alloy, each filled with pellets of refined uranium oxide.

The calandria is filled with heavy water which slows the neutrons and allows the reaction to take place. The pressure tubes are part of a second heavy water system—the one that both cools the reactor fuel and transfers the fuel's heat to the steam boiler.

CANDU reactors produce large amounts of energy. The reactor at Point Lepreau in New Brunswick has a maximum output of 630 megawatts (MW). That's more than enough to supply the electrical demand of five Prince Edward Islands. CANDU reactors are usually even larger; 1260 MW is the preferred size.


Candu Nuclear Power Station
ELECTRICITY
STEAM
STEAM PRESSURE DRIVES TURBINE
HEAT APPLIED TO ORDINARY WATER PRODUCES STEAM
BOILER
REACTOR
TURBINE DRIVES GENERATOR PRODUCING ELECTRICITY
HEAVY WATER COOLANT TRANSFERS HEAT FROM URANIUM FUEL TO ORDINARY WATER IN BOILER (STEAM GENERATOR)
HEAT
HEAT PRODUCED BY FISSIONING URANIUM (NUCLEAR REACTION)
FUEL (URANIUM)
Figure 4.4

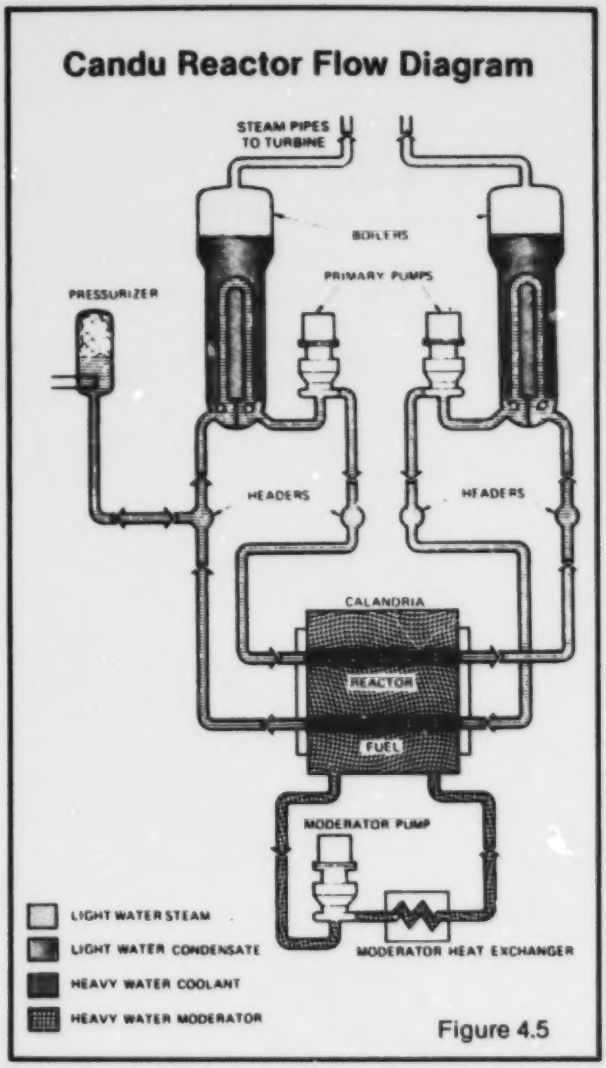


Figure 4.5

The calandria contains the nuclear fuel bundles, and is filled with heavy water. The heavy water slows the neutrons, allowing nuclear fission to take place.

They are also expensive. Nuclear power plants tend to cost more to build than oil or coal plants. (The Lepreau station cost 1.4 billion dollars by the time it was finished in 1983.) Balanced against the higher capital cost of nuclear plants is their lower operating cost. Not yet known is the cost of decommissioning nuclear plants at the end of their useful lives, and the cost of permanently disposing of the radioactive waste produced during their years of operation.

Because P.E.I.'s demand for electricity is much less than the output of a CANDU reactor, it would not be practical to have one on the Island. The Island might choose, however, to buy part of a nuclear plant located somewhere else, and bring the electricity here through a submarine cable. This almost happened with the reactor at Point Lepreau. In 1978 the Island government of Premier Bennett Campbell signed an agreement to purchase power from the Lepreau plant, and to pay part of the construction costs. Many Islanders opposed this, and it became a major issue in the 1979 election campaign. The Progressive Conservatives under J. Angus MacLean opposed the deal, and when they won the election, cancelled the contract.

With P.E.I.'s peak electrical demand being only 113 MW or so, it's clear that a CANDU-sized reactor is inappropriate for the Island. Nevertheless, a smaller reactor might possibly make sense. The Soviet Union has had a small-reactor development program going since the 1950s, and has installed systems in several cities. These reactors range in capacity from 0.75 megawatt to 40 megawatts. France recently designed a 100 MW reactor, and Canada, too, has a family of small units.

Canada's small reactors are called SLOWPOKE reactors. SLOWPOKE-1 and SLOWPOKE-2 were designed primarily for university research. Dalhousie University in Halifax has had a 20-kw SLOWPOKE-2 since 1976. The latest version, SLOWPOKE-4, will be 100 times more powerful. It's a 2 MW unit designed to produce both heat and electricity.

CLASS ACTIVITY

The Nuclear Debate

Nuclear energy, like energy from other sources, has its costs, its benefits, and its risks. When the first atomic bombs were dropped on Japan in 1945, North American newspapers hailed the harnessing of atomic energy as a great step forward. The papers took note of the tremendous amount of energy which is released whenever a small amount of matter undergoes nuclear fission, and they predicted an end to the world's energy problems.

It hasn't worked out exactly that way. From the late 1940s to the early 1960s there was almost universal support for nuclear power. It was seen by a great many people as the best way to generate electricity. In those early days, people focused on positive scenarios, and had total faith that science and technology would solve any problems that arose. A nuclear-power industry came into being, and many reactors were sold.

Countries like the Soviet Union and France remain heavily committed to the nuclear alternative. But in many other countries, public support has waned and reactor sales have declined. Serious accidents at nuclear power stations—the one at Three Mile Island in the U.S. and the Chernobyl disaster in the Soviet Union—helped to intensify public concern.

Now, other concerns—concerns about sulphur dioxide and CO_2 emissions from fossil-fuel generating plants—are causing people to look once again at nuclear power, to once again weigh the pros and cons.

Is nuclear power an acceptable energy option?

That is the question that you and your class will investigate and debate. Can you figure out some way of dividing up the research effort so that all the arguments get covered, and everyone in class learns about the whole issue—yet no one has an impossibly large amount of work to do?

Nuclear Power Reactors in Operation Around the World

(at end of 1986)

Country	Number of Units	Total Capacity (MW)
Argentina	2	935
Belgium	8	5 486
Brazil	1	626
Bulgaria	4	1 632
Canada	18	11 249
Czechoslovakia	7	2 799
Finland	4	2 310
France	49	44 693
Germany, Dem. Republic	5	1 694
Germany, Fed. Republic	21	18 947
Hungary	3	1 235
India	6	1 154
Italy	3	1 273
Japan	35	25 821
Korea	7	5 380
Netherlands	2	507
Pakistan	1	125
South Africa	2	1 842
Spain	8	5 599
Sweden	12	9 455
Switzerland	5	2 932
Taiwan	6	4 918
United Kingdom	38	10 222
U.S.A.	99	84 592
U.S.S.R.	50	27 657
Yugoslavia	1	632
TOTAL	397	273 715

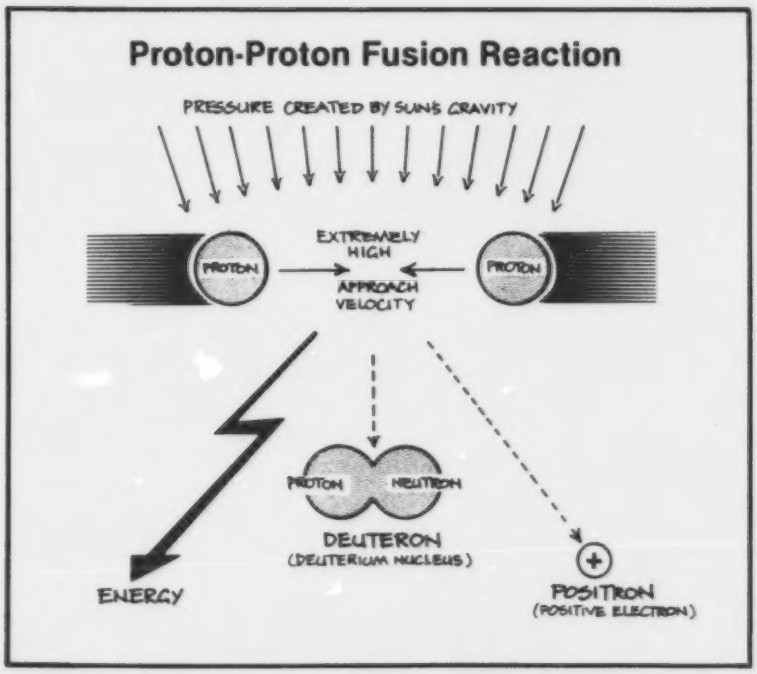
Source: International Atomic Energy Agency (quoted in *Petroleum Economist*).

Nuclear Fusion

Splitting atoms apart (nuclear fission) is not the only way that matter can be converted to energy. Under some conditions, combining simple atomic nuclei to make more complex nuclei releases energy too. This is called *nuclear fusion,* and it's what happens in the sun. There, countless times per second, two hydrogen nuclei combine to make one deuterium nucleus—plus a positron (positive electron), and energy. The sun is actually a gigantic nuclear fusion reactor. And from its location 148 800 000 km away, it's showering the earth with light and heat energy from hydrogen-to-deuterium (and other) fusion reactions.

Hydrogen is readily available here on earth. Physicists recognized many years ago that if nuclear fusion could be created here, in a controlled fashion, it might solve the world's energy problems for all time. Governments too, have recognized the enormous potential benefits. Canada supports some fusion work, but the big spenders are the U.S.S.R., the U.S.A., the European community, and Japan. Together, the world's governments spend two billion dollars a year on this effort. Despite this level of support, creating a sustained and controlled nuclear fusion reaction is proving to be an extremely difficult task.

The basic problem is getting two nuclei close enough to each other to fuse. Physicists now believe that the various forces in nature can be reduced to four fundamental ones: *gravity, electrical attraction/repulsion,* a *strong nuclear force,* and a *weak nuclear force.* The strong nuclear force is one of attraction, and is strong indeed. But it acts only over an extremely short distance. If two hydrogen nuclei (protons) get close enough to each other, the strong nuclear force comes into play, binds the two together, and releases energy.



The proton-proton fusion reaction is the most common fusion reaction in the sun, and the main source of the sun's energy.

Unfortunately, each proton is positively charged. Because of that, protons repel each other. Under all but extraordinary circumstances, the electrical force prevents the two protons from getting close to each other. The game of earthly fusion is to somehow overcome that strong electrical repulsion, and get those protons close enough to each other so that the even stronger *strong nuclear force* can take over and bind them together.

Because the sun contains so much mass, gravity creates a situation of extreme density and pressure at the sun's centre. This brings protons quite close together, despite the electrical repulsion. The interior of the sun is also quite hot—about 13 million °C. The protons, therefore, travel at high speeds. When protons collide head on, as they sometimes do, the combined effect of gravity and velocity gets them close enough for fusion to take place.

On earth we have nothing like the gravitational forces that exist within the sun—so we must accomplish our fusion using high temperature alone. Temperatures, therefore, must be much higher than 13 million °C. This is one aspect of the problem. Others are how to sustain, and contain, fusion reactions once they start.

Many things are being tried. Powerful pulsed lasers are being used to create high temperatures. Strong magnetic fields are being used to bottle up reactions. And the whole problem is being made somewhat easier by using the isotopes of hydrogen—deuterium and tritium—rather than ordinary hydrogen. Without the sun's gravity to help, proton-proton fusion requires impractically high temperatures. Deuterium-tritium fusion, however, occurs at a much lower temperature—a mere 77°C!

Some people predict that fusion energy will become the world's primary energy source within the lifetime of today's high school students. Others predict that it will take much longer—or not happen at all. Whatever the odds, the potential benefits are so great that the world's governments continue to bet their two billion dollars a year on the fusion lottery.

On to Part 2...

You've now reached the end of Part 1 of *ENERGY TECHNOLOGIES: Options for Prince Edward Island.* If you absorbed what you read, participated in the classroom activities, and understood the experiments and problems, you already know a lot about energy. It's quite likely, in fact, that you know more about energy than the average adult. (That's both the good news and the bad news!)

In going through these first four chapters, you've been exposed to some thoughts about what energy *is,* a sense of the key role that energy plays in our lives, and some of the ways in which energy is released, captured, and transformed. You've also come to realize that each form of energy is accompanied by a mixed set of social, economic, and environmental pluses and minuses.

The well-being of Islanders has always depended to a large extent on a fruitful relationship with land and sea. Good soil, productive forests, and a bountiful ocean have been our primary sources of wealth—not industry. P.E.I., it seems, is well suited to biology-based economic activity.

Part 2 of this book deals with the possibility that P.E.I. may also be well suited to biology-based *energy* activity. Part 2 explores the subject of *biomass energy*—energy that originates in the sun, is captured by vegetation, and is made available to us through various products and byproducts of farming and forestry. Part 2 also deals with recovering energy from waste, waste of biological origin and waste from other sources. Finally, Part 2 tries to relate our energy future to that faced by the world as a whole. It concludes that your challenge and the world's challenge are one: finding that elusive path to sustainable development and sustainable *quality of life.* We need ways of living which work for everyone and which will still work when your kids have kids.

PART

2

ENERGY TECHNOLOGIES

Options for Prince Edward Island

Part Two

COPTHORNE MACDONALD

ENERGY TECHNOLOGIES

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Department of
Energy and Forestry

P.E.I. Department of Energy and Forestry, 1989

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To the Student

This book has two aims. The first is to help you get more familiar with energy—its nature, its forms, and the central role it plays in our lives and world. The second aim is to help you appreciate the complex, interconnected nature of our world, and develop wise ways of dealing with that complexity.

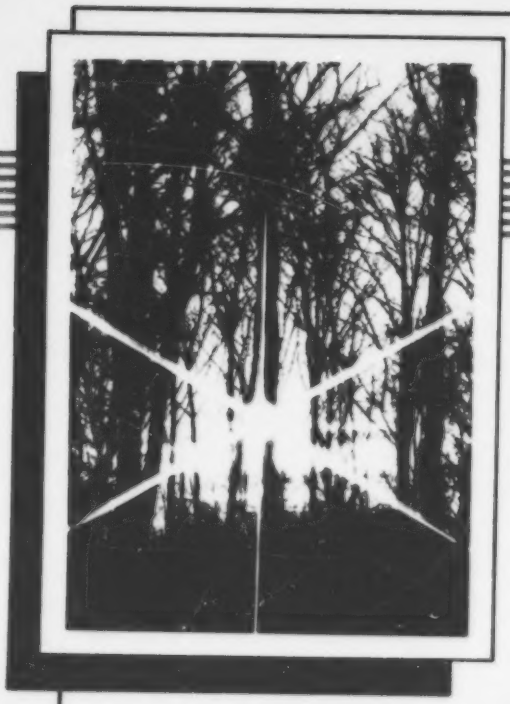
Most people see the world as a hodgepodge of separate, disconnected items and events. The structure of our language reinforces this way of seeing. We say that some things (the subjects) do things (the verbs) to other things (the objects). We also use language to partition human knowledge. We speak of history, social studies, science, and the subdivisions of science as though they were totally separate from each other. This way of seeing is simple, direct, and often useful. But in other situations it turns out to be too simple, and quite damaging.

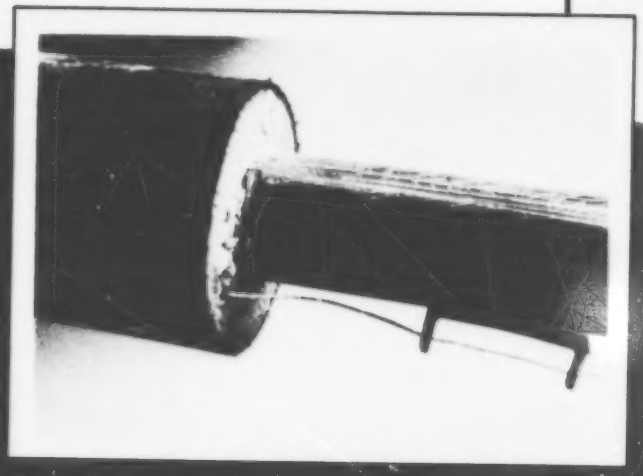
The truth is that we humans are an integral part of a complex, interconnected web. Many of the connections are not obvious, and many people of my generation (and prior generations) ignored them. People focused their attention on "isolated" problems, and often solved them. But the problems weren't really isolated, and the very actions that solved one problem often created others.

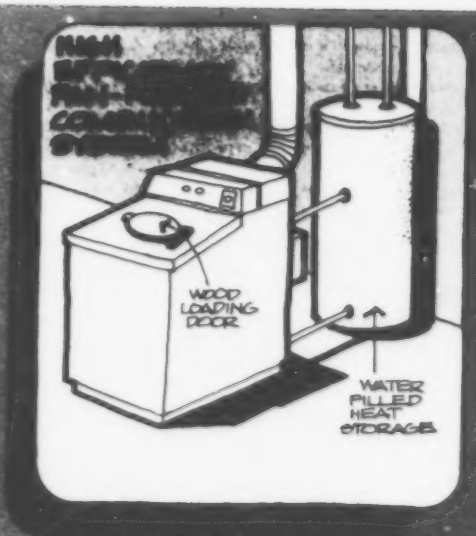
This narrowly-focused approach is no longer acceptable. Through our near-sighted perception of reality we have polluted our environment, depleted our resources, overcrowded our planet, and tampered with many natural processes. To build a better world, your generation will need a new way of looking—a way that sees connections, and finds defect-free solutions and long-term, whole-world answers.

I hope that this course and this book will interest you in developing that deeper, broader, more complete way of seeing and experiencing reality. And, because energy is the foundation of the physical world and involved in every action, I hope that you will get interested in energy. If you do, feel free to use the provincial Department of Energy and Forestry as a resource. You'll find people there who have the broader view. They share the aims of this course, and have worked hard to help bring it to you.

Copthorne Macdonald



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LOADING
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CHAPTER 5

THE BIOMASS OPTION

Biomass Fuels

Biomass Energy

Biomass energy is a form of stored solar energy. In a process called *photosynthesis,* plants use the sun's energy to convert water and CO_2 from the air into sugars. Glucose ($C_6H_{12}O_6$) is the sugar produced in the simplest of the photosynthesis reactions:

$$\text{Energy} + 6\,CO_2 + 6\,H_2O \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6\,O_2$$

The sugars are converted in living cells into cellulose, lignin, proteins, and a host of other chemicals—including hydrocarbons. The tissues of animals and animal waste products contain similar compounds. (Since some animals eat plants, and other animals eat those animals, this shouldn't be too surprising.)

The energy locked up in the chemical bonds of these organic compounds can be released—or converted to more readily useable forms of energy—in a variety of ways. The most common are:

1. **Eating and digestion by animals**—resulting in heat and mechanical energy.
2. **Burning**—to produce heat energy.
3. **Gasification**—heating vegetation in the absence of oxygen to produce hydrogen and carbon monoxide.
4. **Hydrolyzation/Fermentation**—conversion of starches to sugars, followed by conversion of the sugars to ethyl (grain) alcohol by yeast fermentation.
5. **Anaerobic Digestion**—decomposition of plant and animal matter by bacteria in the absence of air to produce methane gas.
6. **Liquification**—conversion of cellulose-rich biomass such as wood into methyl (wood) alcohol.

Being a province rich in farm land, and a province almost half covered by woodlots and forests, biomass energy appears to have special promise here. For this reason, all four of the chapters in Part 2 are devoted to exploring the possible role of biomass energy on Prince Edward Island. In this chapter we will consider the major biomass fuels available to us.

Table 5.1 gives the approximate energy content of many fossil and biomass fuels. The figures refer to the heat of combustion: the amount of energy released as heat when the fuel is completely burned. (In the case of the food items listed, the energy released is approximately the same whether the food is burned or digested.

Energy Content of Fuels

Fuel	Energy Content J/g
Fossil Fuels:	
Coal (Anthracite/hard)	30×10^3
Coal (Bituminous/soft)	32×10^3
Coal (Lignite)	17×10^3
Crude Oil	43×10^3
Diesel & Fuel Oil	46×10^3
Gasoline	48×10^3
Propane	50×10^3
Natural Gas	55×10^3
Biomass Fuels:	
Wood (10% moisture)	19×10^3
Straw (dry)	17×10^3
Dung (dry)	17×10^3
Garbage/Trash (35% moisture)	10×10^3
Biogas	36×10^3
Ethanol (Grain Alcohol)	27×10^3
Methanol (Wood Alcohol)	20×10^3
Bread	10×10^3
Butter	33×10^3

Table 5.1

Note the similarity in energy values from fuel to fuel. The energy content of most of them differs by less than a factor of two from middle-of-the-range fuels like coal and butter.

Human Wastes

Household Garbage

The Garbage Book estimates that the average Canadian discards about 1.8 kilograms of garbage per day. More than half of this is said to be generated at home, the rest at work, school, or elsewhere. This estimate applies to Islanders, too. Each year about 30 million kilograms of garbage goes to P.E.I's Energy-From-Waste plant in Parkdale. That garbage is produced by about 45 000 Islanders—35 per cent of the Island population. Dividing the total amount of garbage by the number of people and days in the year gives that same figure of 1.8 kg per person per day.

It takes a lot of energy to make the products and packages we buy. Energy is needed to extract the raw materials, to refine them, to manufacture them into final products, and to ship these products around the country. Most of this energy cannot be recovered. Thus, the most energy-efficient course of action is not to create waste in the first place. By reducing our garbage and trash as much as possible—by reusing and recycling and repairing products—we avoid wasting the energy that was originally expended to extract, refine, manufacture, and ship.

Having said that, it still makes sense to put whatever waste we do have to the best possible use. And with the energy content of average household garbage being 10 000 joules per gram, it's clearly a valuable energy resource. As we will see in the next chapter, special burning techniques are needed to extract energy from garbage cleanly and safely—to do it without putting unpleasant odours and dangerous chemicals into the air.

CLASS PROJECT

Are there volunteers in the class willing to keep track of all the garbage and trash which they and their families discard during a week?

The experimental procedure needs to be defined beforehand. The whole class could plan the experiment, even though not everyone will collect data. To what extent should different types of garbage and trash be accounted for separately? And what techniques might be used to make the data collection easier? (One possibility would be to put different types of waste in different garbage bags. Food waste could be put in one bag, packaging materials in another, etc. These bags could then be weighed on a bathroom scale before the garbage and trash is disposed of.)

Using the data that the volunteers bring to class, discuss the pros and cons of *recycling* various types of refuse here on P.E.I.

Sewage

Sewage contains both heat energy and chemical energy. Heat energy can be extracted from liquid sewage with a heat pump. Such a system would be much like the system used in the Prince Edward Hotel to extract heat from well water, as discussed in Chapter 4. However, because sewage is warmer than well water, the system's coefficient of performance (COP) would be higher.

The two most common sewage treatment processes both rely on bacterial action to decompose the sewage. The first of these processes involves *aerobic* bacteria—bacteria that thrive in the presence of oxygen. Here, air is pumped into open sewage lagoons, and the aerobic bacteria break the sewage down into relatively simple chemicals.

Anaerobic digestion is the other technique. It uses entirely different types of bacteria, types that thrive in the *absence* of oxygen—*anaerobic* bacteria. This process not only breaks down the sewage, it also generates methane gas (CH_4)—a valuable energy source.

The biological process in this second type of sewage treatment plant is complicated, and not fully understood, but is thought to take place in three stages. First, large organic molecules are decomposed into smaller molecules such as sugars and amino acids. Second, these smaller compounds are converted to organic acids. Third, the organic acids are converted into the gases methane (CH_4) and carbon dioxide (CO_2).

Agricultural Wastes

Manure

In many parts of the world (particularly hot, dry countries), sun-dried animal dung is collected and burned as a cooking fuel. In North America the most common way of extracting energy from manure is anaerobic digestion—the process just described. Here, a slurry of manure and bacteria in an oxygen-free environment generates methane gas.

Straw

As a byproduct of grain production, P.E.I. produces approximately 190 000 tonnes of straw each year. Roughly one third of this is used for animal bedding; another third is left in fields and is plowed under to add organic matter to the soil. The remainder—as much as 70 000 tonnes—is available for sale or for use on the farm as an energy source. Straw is high in cellulose, and cellulose-rich materials do not decompose readily in an anaerobic digester. A better way to release the energy is to burn it.

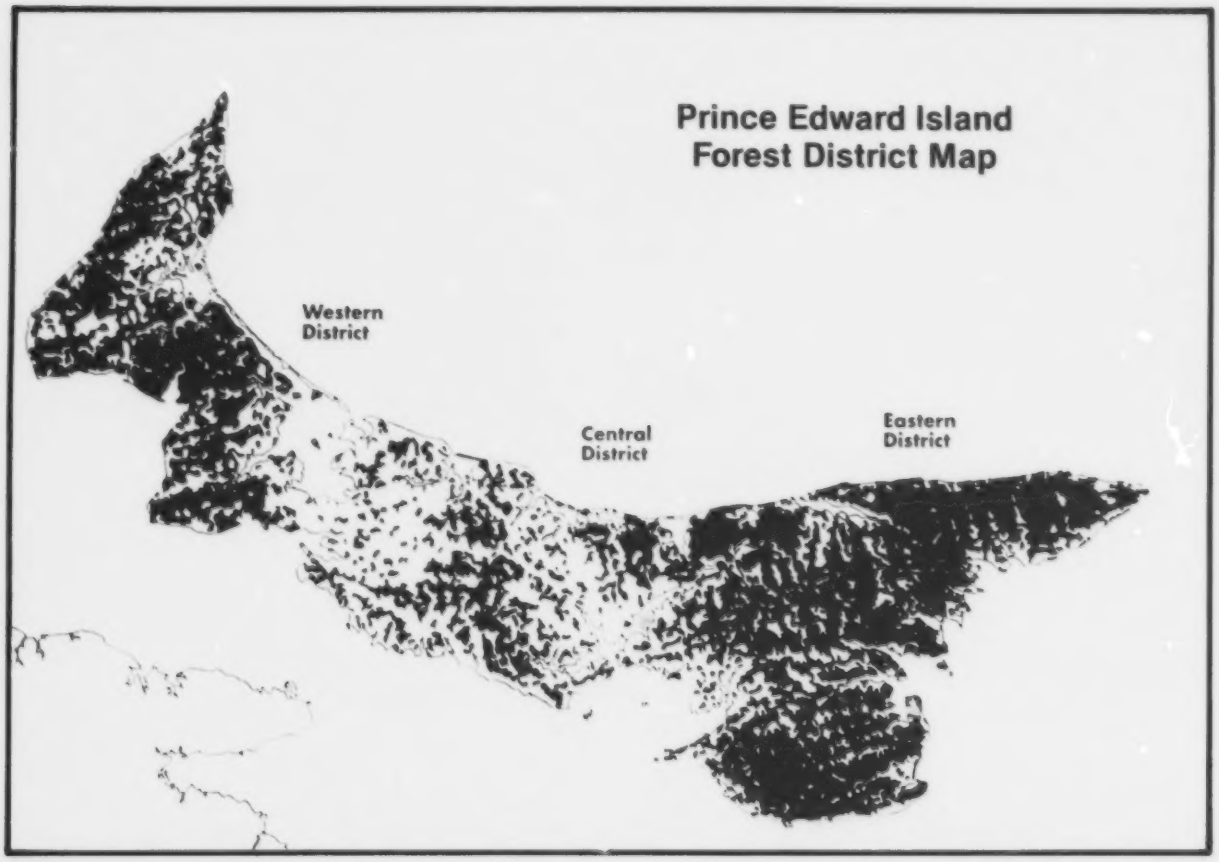
Manufacturing Wastes

P.E.I. is not highly industrialized, so we don't have a large variety of manufacturing wastes to turn into energy. We do, however, have a number of sawmills that convert saw logs into lumber. These mills produce sawdust, bark-covered slabs, and other wood residue

as byproducts of their operations. Other firms, such as cabinet shops, also produce sawdust and scrap wood. Using the right kind of combustion systems, these waste products can be burned, generating heat for useful purposes.

Wood

With nearly half the Island forested, wood is the biomass fuel that gets most attention here. Wood has always been a major residential heating fuel on P.E.I. According to the 1986-87 P.E.I. Fuelwood Survey, approximately 55 per cent of Island households still use wood as a fuel. These 23 000 households consume an average of 5.6 cords per year. Total roundwood consumption during the 1986-87 heating season was 129 000 cords, or 258 000 green tonnes. (Green wood has 45 to 50 per cent moisture content.) About 75 per cent of this was hardwood; 25 per cent was softwood.



Almost half the land area of P.E.I. is covered by forest.

The Island has much softwood, but Islanders have traditionally preferred to burn hardwood in their wood stoves and furnaces. Residential wood use has increased to the point where the yearly demand for hardwood is greater than the yearly hardwood growth in those woodlots available for cutting. In Chapter 8 we will learn about the steps being taken to correct this situation. Nevertheless, it's clear that any expansion of our use of wood for energy must concentrate on softwood.

In contrast with the substantial use of wood for residential heating, very little has been used in the commercial, institutional, and industrial sectors. Fuel in the form of roundwood logs, while suitable for hand-stoked appliances, is not attractive for large establishments. They need fully automated combustion systems. A new form of wood fuel—wood chips made from forest residue—is the promising fuel for these users.

Wood chip fuel is made from poor-quality whole trees and from tree-harvesting residues like tops and branches. Chips can also be made from sawmill residues, and in Sweden even the stumps and roots of trees are chipped. A machine called a *chipper* takes in this great variety of woody material and puts out small pieces that are fairly uniform in size. Typically, these wood chips are then blown or dumped into transportable bins, and the bins are taken by truck from the woods directly to user facilities.

We will be exploring many questions about wood chips in the coming chapters. But let's face one concern here: the size of the resource. With barely enough hardwood to meet current needs, are we sure that there is enough wood to chip?

Figure 5.1 indicates that the answer is yes, we have more than enough for all projected uses. There is an immense amount of available forest biomass today, and with reasonable forest management, there will continue to be a comparable amount in the future. **Hardwood for logs is in short supply, but wood suitable for chipping definitely is not.**

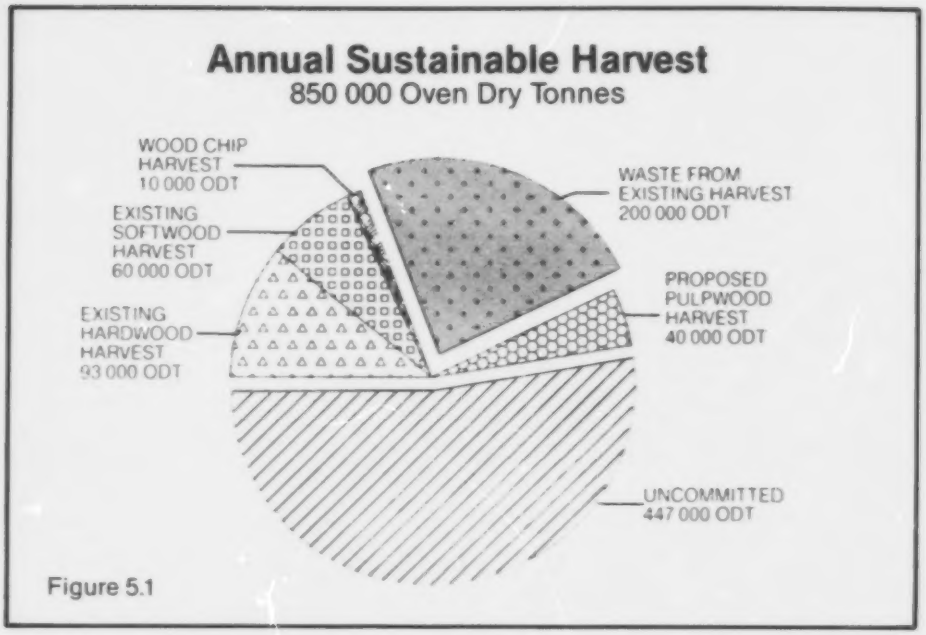

Annual Sustainable Harvest
850 000 Oven Dry Tonnes
WOOD CHIP HARVEST 10 000 ODT
EXISTING SOFTWOOD HARVEST 60 000 ODT
EXISTING HARDWOOD HARVEST 93 000 ODT
WASTE FROM EXISTING HARVEST 200 000 ODT
PROPOSED PULPWOOD HARVEST 40 000 ODT
UNCOMMITTED 447 000 ODT

Figure 5.1

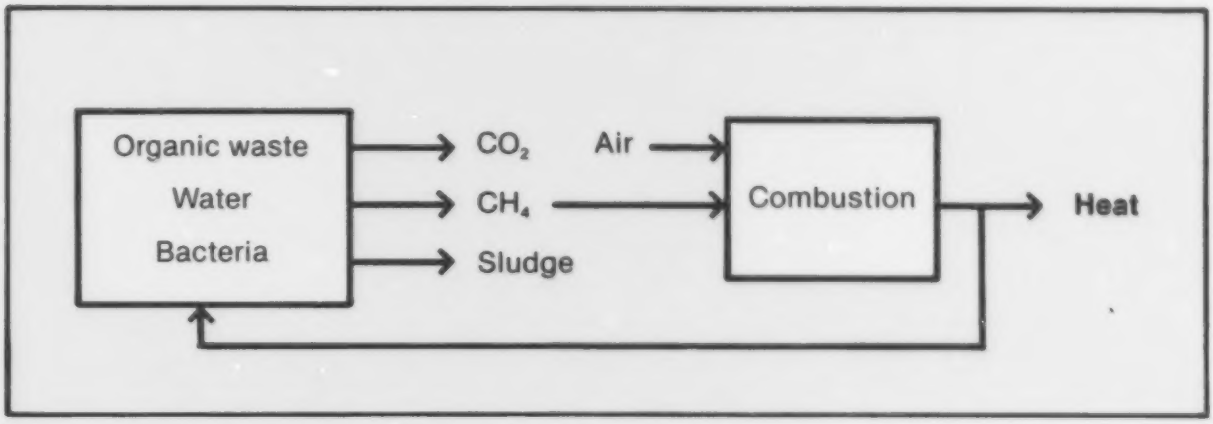
In the three chapters that follow we will explore the potential of wood chips and other forms of biomass energy to improve our present energy situation:

- In Chapter 6 we investigate biomass-to-energy conversion systems—everything from garbage incinerators and methane generators to roundwood stoves and wood chip combustion units.
- In Chapter 7 we look at various ways of distributing biomass-created energy. We move from one-building heating systems, to many-building *district heating* systems, to *co-generation* systems that send both electrical and heat energy to customers.
- Finally, in Chapter 8 we look at the interesting and crucial matters of wood resource management, environmental impacts, and possible directions for the future.

CHAPTER 6

THE BIOMASS OPTION

Biomass-to-Energy Conversion Systems



In anaerobic digestion, bacteria (in the absence of oxygen) break down complex organic molecules into simpler ones—including methane gas (CH_4), a valuable energy source.

Methane or "Biogas" Generators

Figure 6.1 shows a typical biogas generation system. The heart of the system is the anaerobic digester. This unit is an air-tight chamber in which organic waste is broken down by bacterial action, creating biogas in the process. Biogas is 60 to 70 per cent methane (CH_4). The remainder is largely carbon dioxide (CO_2), with small amounts of other gases such as hydrogen sulphide (H_2S). The carbon dioxide contributes nothing to the energy content of the gas, but for most purposes it causes no harm.

Also produced within the digester, as a byproduct of the digestion process, is a semi-liquid nitrogen-rich sludge. If not contaminated with heavy metals and other biologically dangerous chemicals, both the liquid and the solids are valuable as fertilizers—and have much less odour than manure.

Digesters must be designed to allow fully or partly digested sludge to be removed, and new organic matter to be added. In the system shown, new material—in semi-liquid form—enters near the bottom of the tank. Byproducts are drawn off higher up. This adding and removing must be done in a way that prevents air from

entering the system. Mixtures of methane and air can be highly explosive.

The rate of biological activity increases when the digester contents are kept mixed. Stirring is sometimes accomplished by motor-driven paddles; sometimes by biogas that is pumped back into the bottom of the digester to bubble up through the slurry. The rate of activity also increases when the contents are kept at about 35°C—a temperature at which many varieties of anaerobic bacteria thrive. In our climate, this means that the digester contents must be heated.

In China and other less-developed countries, biogas is used primarily for cooking. In P.E.I., the favored uses are generating electricity and heating buildings. Gasoline-type engines run quite well on biogas, and biogas can be substituted for propane (C_3H_8) or natural gas (CH_4 + other gases) in gas-fired boilers.

Biogas generation makes particular sense in situations where there is an abundance of organic waste that needs treatment anyway. There are some interesting future possibilities, such as producing biogas from cull potatoes. But we'll look here at three Island situations where biogas generation has already been tried:

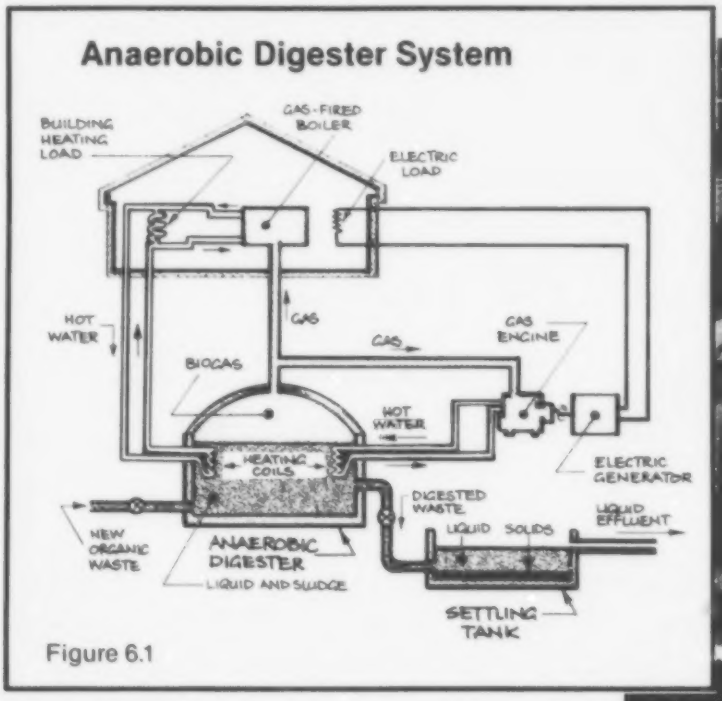
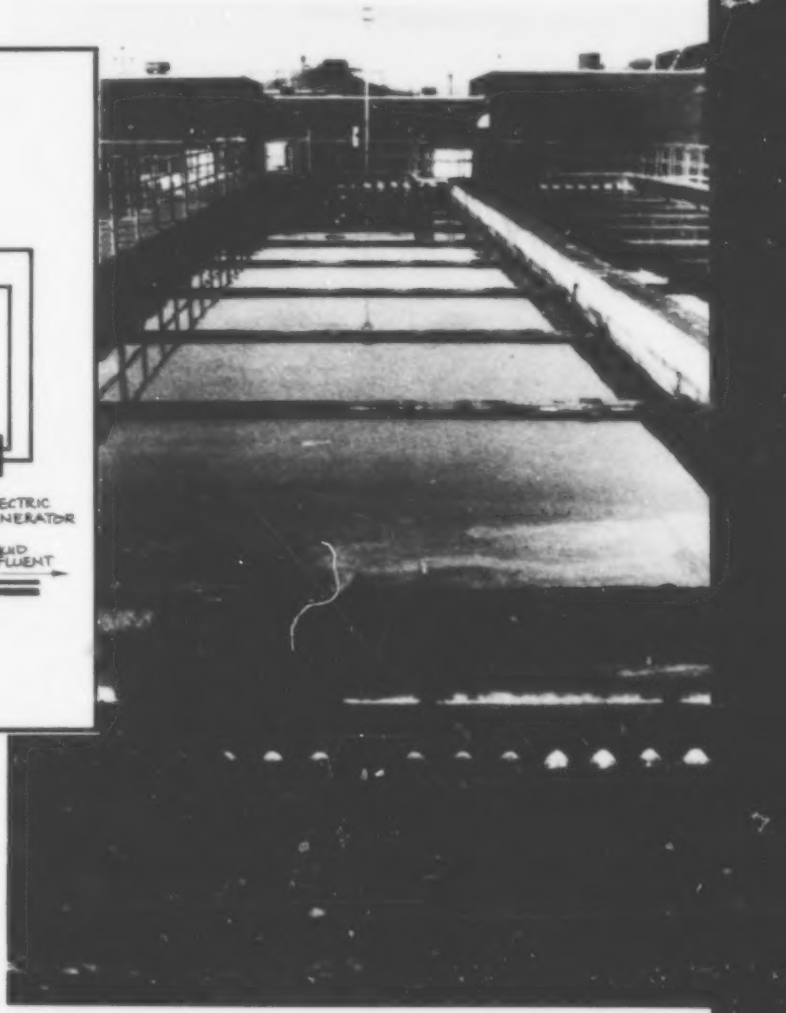


Figure 6.1

Biogas is 60 to 70 per cent methane (CH_4). The remainder is largely carbon dioxide (CO_2), with small amounts of other gases such as hydrogen sulphide (H_2S). Gasoline-type engines run quite well on biogas, and biogas can be substituted for propane or natural gas in gas-fired boilers.



This primary sewage treatment plant in Parkdale uses anaerobic digestion to decompose Charlottetown-area sewage. The building is heated by the biogas produced. Surplus gas is used to generate electricity.

1. Biogas from Sewage

The Charlottetown Area Pollution Control Commission operates a primary sewage treatment plant on Riverside Drive in Parkdale. There, raw sewage is subjected to anaerobic digestion.

The incoming sewage is quite dilute, so it is concentrated, through settling, into a liquid containing about three per cent solid matter. The plant feeds this concentrate—90 000 litres per day of it—into the plant's digester. The same amount of largely-digested material is simultaneously removed from the digester and put into a sludge settling tank. There, the solids are allowed to settle out.

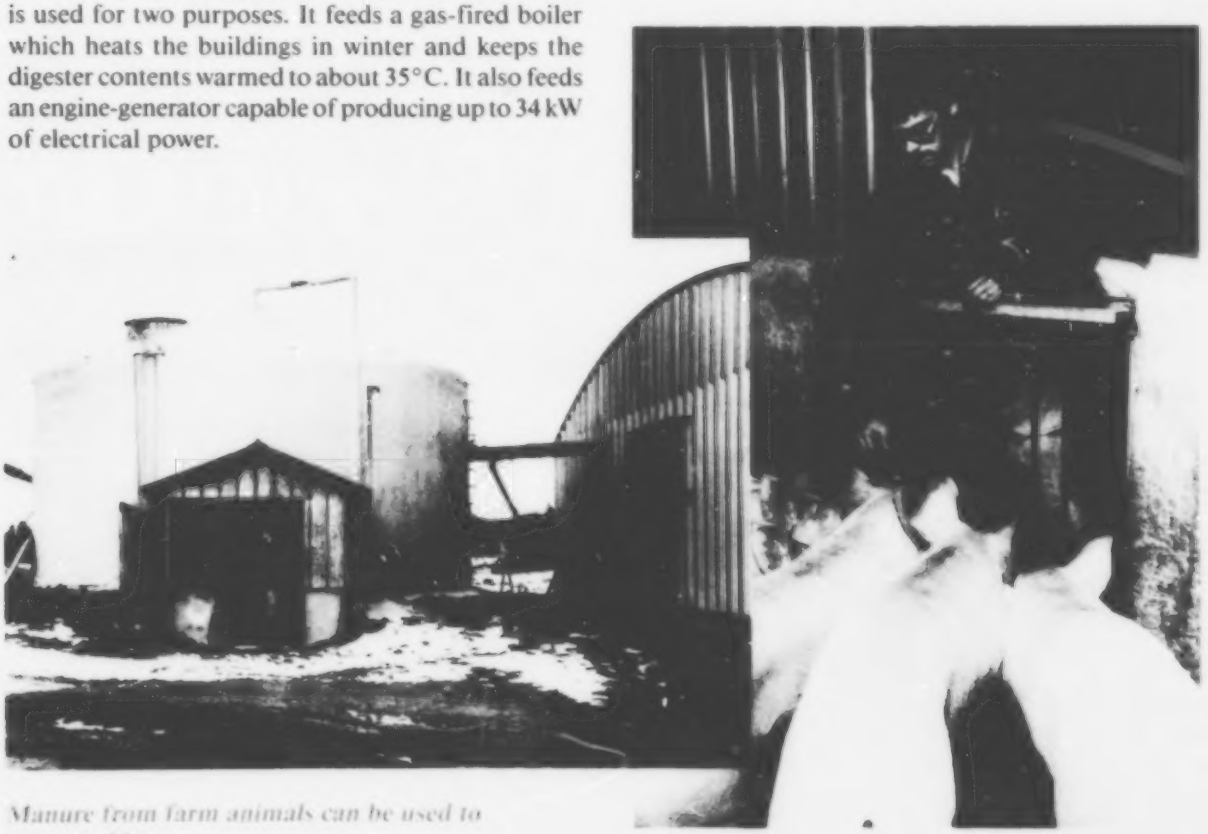
The digester capacity is slightly more than two million litres—that's roughly 22 times the daily input. This means that incoming sewage is subjected, on average, to 22 days of bacterial action. The digested solids are removed periodically from the settling tank, and hauled away for use as fertilizer.

The biogas produced at the sewage treatment station is used for two purposes. It feeds a gas-fired boiler which heats the buildings in winter and keeps the digester contents warmed to about 35°C. It also feeds an engine-generator capable of producing up to 34 kW of electrical power.

2. Biogas from Manure

An interesting experimental system was built at Linden Lee Farms in Meadowbank. The farm operates a hog finishing operation. The gas system was designed to accommodate the manure output from 2000 hogs—about 19 000 litres per day. The 6.7 m diameter, 6.4 m high digester is large enough to hold about 10 days' output of manure, and was designed to produce over 400 m^3 of biogas daily when fully loaded. The gas is piped to a Caterpillar engine that turns an electrical generator. That much gas is capable of producing a continuous 27 kW electrical output from the engine-generator set, but the system has never been run at full output. The engine also produces a substantial amount of heat—heat used to keep the digester contents warm.

As fresh manure is added to the digester, processed material is removed and stored in a nearby lagoon. From time to time this material is spread on fields as a fertilizer.



Manure from farm animals can be used to generate biogas.

3. Biogas from Potato Processing Waste

A third waste-processing biogas system is located at the Cavendish Farms facility in New Annan—a plant which produces frozen french fries. The plant is a large energy consumer—one of the Island's largest. It is also a plant with a serious waste-disposal problem. It must dispose of its sizable output of potato processing waste in an environmentally sound manner. Anaerobic digestion was chosen as a way of attacking both problems at once.

The digester at Cavendish Farms is roughly the size of a football field, and holds up to 45 million litres of peel/water slurry. The system was designed to handle 4.5 million litres of new material each working day. The gas produced is consumed by two engines, each of which drives a 425 kW electric generator. Fed with sufficient biogas, these engine-generators could deliver several million kilowatt-hours of electricity per year. The normally wasted, low-grade heat from engine block cooling and engine exhaust is used to raise the temperature of the digester contents. As of late 1988, this system was still being refined.

This large anaerobic digester at Cavendish Farms in New Annan decomposes potato processing waste, and produces biogas-generated electricity for the plant.

Straw Combustion

Straw is being used to a limited extent as a heating fuel on P.E.I. A particularly interesting straw-burning system is the one at Lea Schurman's farm near Kensington.

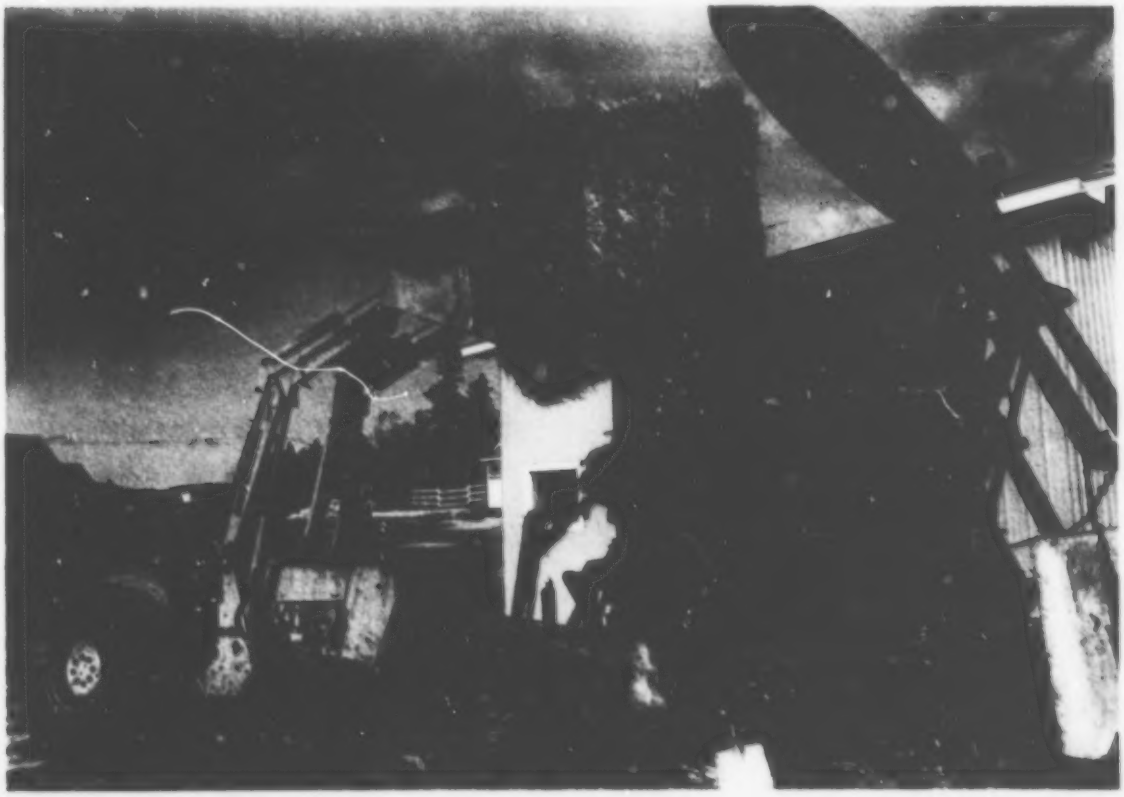
Mr. Schurman grows 90 per cent of the grain he needs to raise 1200 feeder hogs and to fatten 200 cattle each year. Along with the grain comes straw: 800 of those large, round 455 kg bales in a typical year. Mr. Schurman has always used some straw for bedding purposes, but formerly left the remainder lying in the field. Now he bales the extra straw and uses it as a fuel to heat two of the farm's buildings.

Mr. Schurman is pleased to be making better use of a waste product of his operation, and reports that the labour involved is minimal. It takes only a couple of days to put up a winter's supply of straw.

The system's combustion chamber is designed to take one whole bale at a time. A forced-air draft aids the burning, and the entire bale is consumed in about three hours. The heat released during combustion raises the temperature of the water in a 14 000 litre insulated storage tank to 80 or 90 degrees C. This hot water then travels through buried insulated pipes to the buildings requiring heat. There, it circulates through radiators.

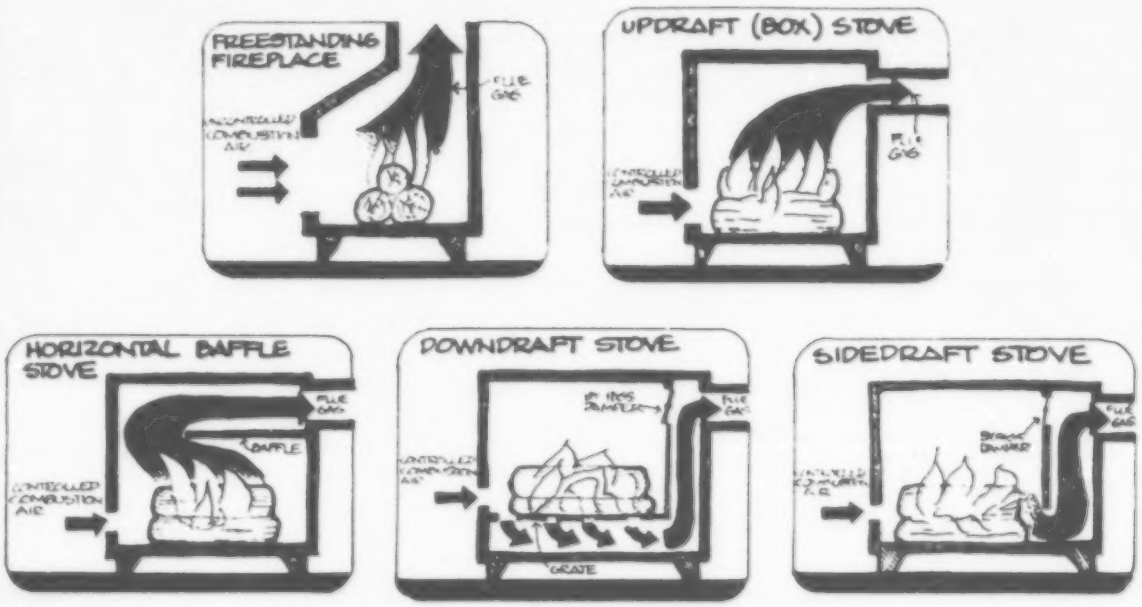
The Schurmans find that burning one bale a day is usually enough to keep the buildings comfortable, so "feeding the fire" takes little of their time. Maintenance hasn't been a problem either. They find that the straw doesn't leave much ash, and that cleaning the combustion chamber once a month is usually enough.

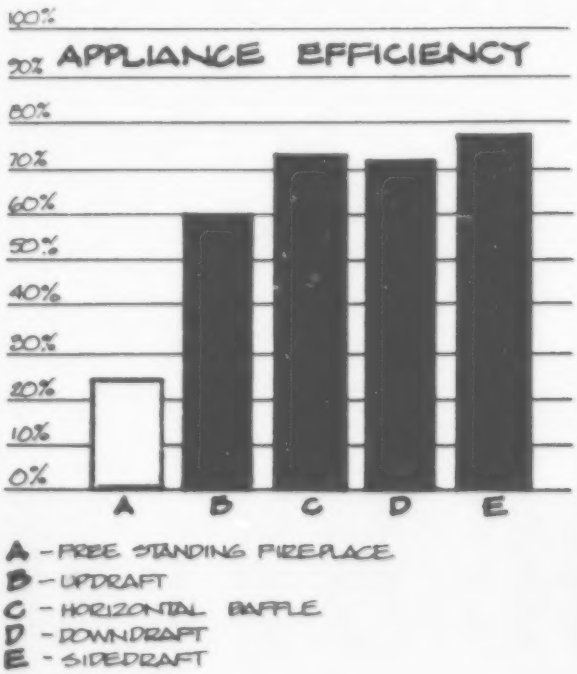
The oil bill for heating these buildings used to be $5000 a year, but the new straw-burning system has eliminated most of that.



Farmer Lea Schurman of Kensington loads a large bale of straw into the combustion chamber of his farm's heating system. The system heats several buildings, and burning one bale a day is usually enough to keep them warm.

Wood Space Heaters





The Canadian Combustion Research Laboratory of Energy, Mines and Resources Canada has conducted tests on the performance of five different types of wood space heaters. These tests showed that a fireplace or non-airtight stove is very inefficient. Airtight stoves that are well designed and constructed can achieve efficiencies as high as 78 per cent.

Figure 6.2

Residential Roundwood Heating Systems

Many Islanders use roundwood and split logs as their primary source of heat; many others use wood to supplement the heat they get from oil.

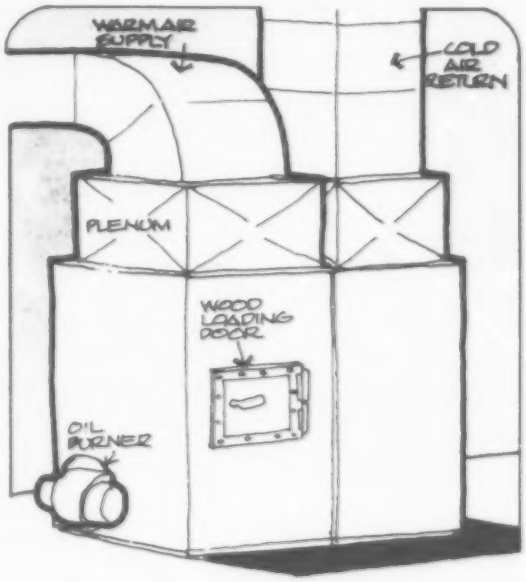
Wood space heaters (wood stoves) are the most common type of combustion unit. The efficiency with which they convert wood energy into useful room heat varies considerably. Figure 6.2 compares the efficiency of several types. Note the poor efficiency of the first unit, the freestanding fireplace. In units like this which have an unrestricted flow of combustion air, the wood tends to burn rapidly. Rapid burning, combined with the small heat transfer area of this particular design, results in little heat being transferred to the room. Most of it goes straight up the chimney.

The other stoves shown are so-called "airtight" models. These units are built with close-fitting door seals and adjustable air intakes to allow the incoming combustion air to be set at the desired level. Restricting the air flow has two advantages. First, the efficiency goes up—as the graphs indicate. Second, the fire can be made to burn for a much longer time between refuelings. Many airtight stoves will burn fuel all night or all day without attention.

Slow burning, however, also has a disadvantage: greater creosote buildup in stovepipes and flues. With any wood burning appliance, the inside of the chimney and stovepipes must be inspected regularly to detect creosote buildup. And to avoid the possibility of dangerous flue fires, any buildup of 6 mm or more must be cleaned out. With airtight stoves, inspection and cleaning have to be done more often than with hot-burning appliances such as freestanding fireplaces or stoves having loose-fitting doors.

Wood-fired furnaces and boilers are also used for residential heating. These devices often look much like oil-fired units, and some are designed to burn either wood or oil. Wood-fired hot air furnaces deliver heat to various rooms in the house through air ducts in the same way that an oil-fired unit would. Some wood-fired hot water boilers also distribute their heat in the conventional manner. But in hot water systems there is a second option: using water to store heat for later use.

Wood-fired heat-storing systems use the same basic approach that farmer Lea Schurman uses in his straw-burning system. A firebox load of wood is burned rapidly in a forced-draft fire, and the water heated by this hot, short-duration burn is stored in an insulated tank for later use. Despite the fast burn, these systems are efficient. Their boilers are designed to transfer most of the heat of combustion to the water before the combustion gases reach the flue.



WOOD-OIL COMBINATION

Wood-oil combination furnaces can help make wood burning convenient. Wood is used when someone is home to load it into the furnace, and oil is used at other times.

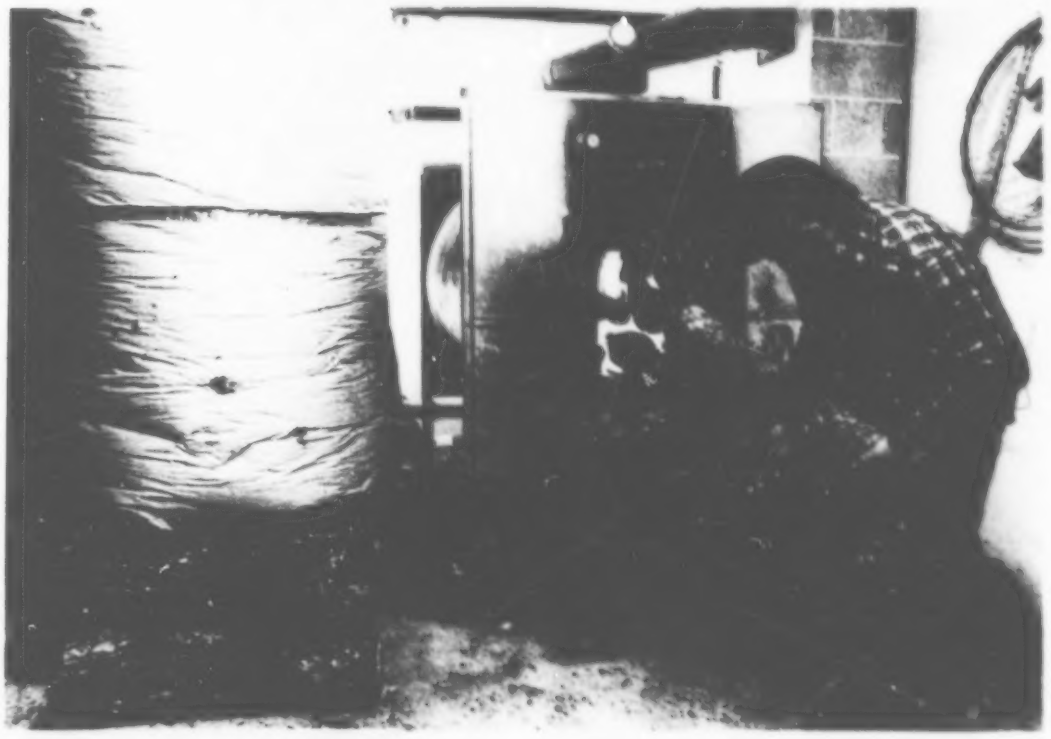
Using Water To Store Heat

Using water as a heat storage medium sounds like a good idea, but what are the particulars? How much energy will water store? To what temperature do you heat it? How much water do you need in order to store a given amount of heat energy?

The energy content of one gram of liquid water increases by 4.2 joules for each degree C that its temperature is raised. This factor, 4.2 J/g°C, is known as the **specific heat capacity** of water. It is the key to solving problems in which water is used to store heat energy.

Sample Problem:

You are thinking of buying a fast-burn forced-draft wood boiler with a firebox that holds 50 kg of wood. You want to know how large a tank of water will you need to store the heat energy released when that 50 kg of wood is burned. Assume that the wood has 10 per cent moisture content, that the boiler has a rated efficiency of 75 per cent, and that you want to heat the water from an initial temperature of 35°C up to 85°C. (You don't want the water to reach the boiling point, and that's why you chose 85°C as the upper temperature.)



Wood combustion systems can be linked to heat storage such as the tank of water shown above. This combination allows efficient high-temperature combustion of the fuel, and evens out the heat delivered to the living space.

Solution:

From Table 5.1 in the last chapter we know that wood with 10 per cent moisture has an energy content of about 1.9×10^4 joules per gram. Thus, the energy content of 50 kg of wood is:

$$1.9 \times 10^4 \text{ J/g} \times 5.0 \times 10^4 \text{ g} = 9.5 \times 10^8 \text{ J}$$

When it is burned, the energy transferred to the water will be 75 per cent of that:

$$9.5 \times 10^8 \text{ J} \times 0.75 = 7.1 \times 10^8 \text{ J}$$

Since the temperature of the water will be raised by (85°C - 35°C) = 50°C, the energy stored in the water will be:

$$50°\text{C} \times 4.2 \text{ J/g°C} = 210 \text{ J/g}$$

Therefore, the number of grams of water needed is:

$$7.1 \times 10^8 \text{ J} / 2.1 \times 10^2 \text{ J/g} = 3.4 \times 10^6 \text{ g}$$

Since 1 g of water occupies 1 cm^3, and there are 1000 cm^3 in a litre, the minimum storage tank volume required is:

$$3.4 \times 10^6 \text{ g} \times 1 \text{ L} / 1 \times 10^3 \text{ g} = 3.4 \times 10^3 \text{ L}$$

Assigned Problem:

You burned 50 kg of wood in your wood boiler, and when the burn ended the insulated water tank contained 3.4×10^3 L of water at 85°C. You then left for the day, and while you were gone, your heating system's water pump circulated the hot water through the baseboard radiators in your house. You returned 8 hours later, and found that the temperature of the water in the tank had dropped to 43°C. How much heat energy was transferred from the water to the interior of the house during your absence?

EXPERIMENT

Determining the Specific Heat Capacity of Other Materials

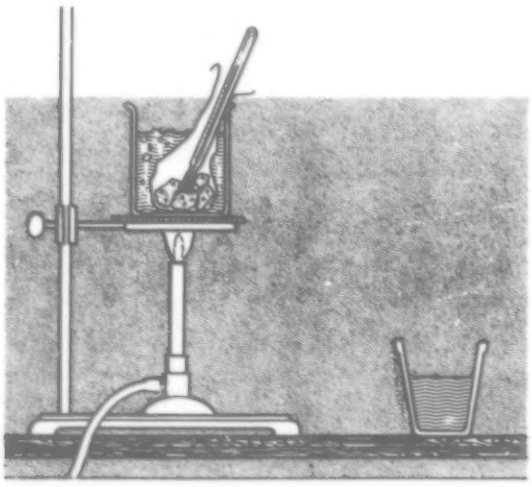
Introduction

Water is only one of many materials that can be used to store heat. Sometimes, for example, modern houses are built with insulated concrete foundations. Insulation is laid under the basement floor before it is poured, and between the basement walls and the earth. The concrete then acts as a large "heat sink," absorbing heat when the basement air temperature is higher than that of the concrete, and giving off heat to the air when the situation is reversed.

If you were thinking of building a house with a foundation like this, you would be interested in the heat capacity of concrete. How does concrete compare with water as a heat storage medium? You can run an experiment to find out.

Materials

A large styrofoam cup, 400 mL beaker, plastic bag, Bunsen burner, ring clamp, wire screen, retort stand, 2 thermometers, balance, tongs, matches, graduated cylinder, and small pieces of concrete having a mass (all together) of about 200 g.



Procedure

Record the total mass of the concrete pieces and put them in the plastic bag. Fill the beaker ⅔ full of water, and place the bag in the beaker.

All the concrete should be below the surface of the water, but the top of the bag should be above. The idea is to heat the concrete to 100°C without getting it wet. Insert a thermometer into the bag, resting the bulb against concrete, not against the bag. Bring the water to a boil, and allow it to boil for several minutes after the indicated temperature has stopped rising.

Pour 200 mL of room temperature water into the styrofoam cup. Record its mass and temperature.

Remove the thermometer from the bag. Then, using the tongs, remove the plastic bag from the beaker of boiling water, and immediately pour the concrete pieces into the syrofoam cup.

Using one of the thermometers, monitor the temperature of the water in the cup, and record the highest reading you get.

Calculations and Conclusion

When the hot concrete is put into the water, the temperature of the water rises and the temperature of the concrete fails until the two are at the same "equilibrium" temperature.

1. The concrete, at that point, will have lost heat energy, and the water will have gained heat energy. The first law of thermodynamics—the law that says energy is conserved—implies that the amount of heat lost by the concrete equals the amount of heat gained by the water. Express this in an equation, and solve for the specific heat content of the concrete.

2. For a given mass, which material stores more heat, water or concrete? How many times more?

Wood Chip Combustion Units

Wood chip combustion is simple in principle, but as Figure 6.3 indicates, complete systems tend to be complex. This schematic drawing shows two views of the wood chip combustion system at the University of Prince Edward Island—the largest wood chip system on the Island as of the late 1980s. The upper view highlights the wood chip feed and ash removal systems. The lower view highlights the combustion process.

Starting with the upper view, we see that the U.P.E.I. system uses underground chip storage. Large motorized doors cover the concrete storage bin, and retract to permit a whole truckload of chips to be dumped at once. In the storage bin, wedge-shaped scrapers under the chips move them toward the output end of the bin. There, the chips drop into a small holding pit from which they are transported upward through a pipe by a rotating feed screw or "auger"—a device that dates back to the days of Archimedes in ancient Greece.

Moving now to the lower view, we see that the wood chips make a sharp turn and climb slightly higher to the fuel input opening in the primary combustion chamber. This chamber has a moving floor of iron steps which slowly descend, carrying the chips through the chamber. Combustion air enters through this mov-

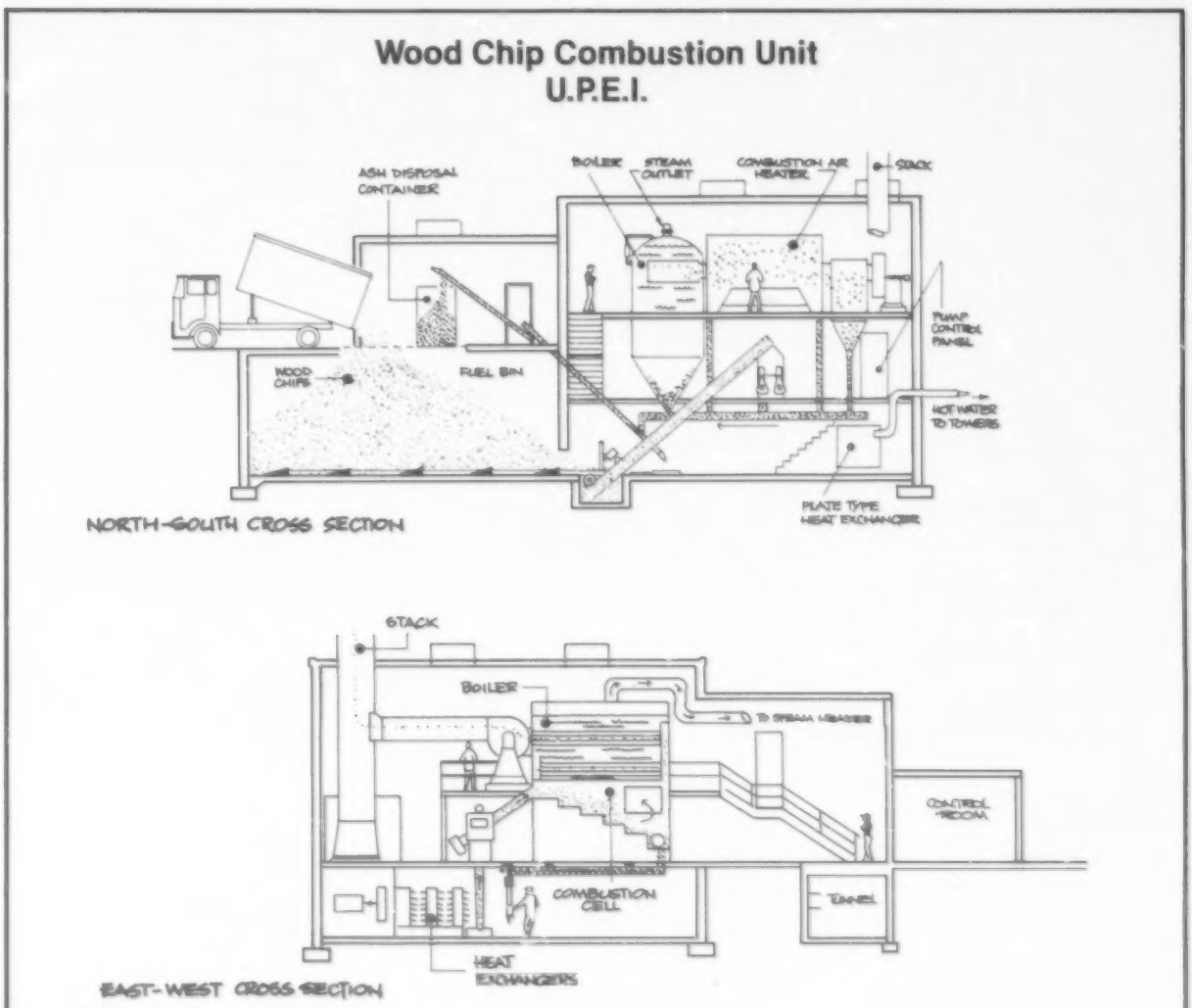


Figure 6.3

Two views of the wood chip combustion unit at the University of Prince Edward Island.

ing floor, and through holes in the side walls. By the time the chips have reached the lower-right end of the chamber, the only solid material remaining is a little ash. This ash is fed out of the chamber, and wends its way through another auger-feed system to an ash collection barrel near the wood chip bin.

Most of the combustion takes place in the primary chamber. The hot gases produced by the combustion process, along with some final licks of flame, then enter a secondary "burn-out chamber" in the lower part of the boiler. Combustion is completed there. Next, the fully-burned gases pass through the boiler. On the way through, they transfer most of their heat to the boiler water, turning it to steam.

Returning to the upper view, we can see that the boiler exhaust gases do not go directly to the stack. Instead, they first pass through chambers which allow fly ash and other solid particles to settle out.

This U.P.E.I. system is a microcomputer-controlled system—as are all P.E.I.'s institutional wood-chip systems. It is computer control that has made wood heat practical for institutional, industrial, and commercial users. In the U.P.E.I. system, the microcomputer is connected to sensors which monitor key parameters like steam pressure, air pressure in the smokestack, combustion chamber temperature, and several others. Then, based on the data from these sensors, the microcomputer sets the rate at which chips are fed into the primary combustion chamber. It also regulates the flow of combustion air. The result is efficient burning at all times, with low stack emissions.

The maximum rated heat output of the U.P.E.I. system is 3.6 megawatts. That's 3.6 million joules per second. In the course of a year's operation the system consumes about 9000 tonnes (9 million kilograms) of "green" wood chips.

U.P.E.I.'s original oil-fired boilers are still used to some extent. Wood boilers are normally sized to provide 70 to 80 per cent of the total heat energy required during a year, but only 30 to 40 per cent of the *peak* energy—the energy required on the coldest days. During very cold weather the oil-fired boilers fire up and produce supplementary heat. This approach is used because a wood boiler large enough to handle the full peak load would be underloaded most of the time, and operate inefficiently.

Don Coles, Director of the Physical Plant at U.P.E.I., has called the system a "beautiful operation." He is especially happy with its cleanliness. "The system creates only one 45 gallon drum of ash in a week's burning. The bunker-C oil we have been using is dirty, variable in quality, has a high sulphur content, and you must heat it to get it to flow. Wood is much cleaner."

Wood chip delivery at U.P.E.I.

P.E.I. Schools Lead in Wood Energy Use

Among the Island's major users of wood chips are our schools. It also appears that P.E.I. is far ahead of other provinces in the use of wood for school heating.

Back in 1982, the P.E.I. Energy Corporation, in cooperation with Regional Administrative Unit No. 4 at the east end of the Island, installed the first wood chip system in an Island school. Now Unit 4 has three wood combustion systems in place, providing heat to five schools. The combustion systems are located in the unit's three regional high schools—Montague, Souris, and Morell. Through underground pipes, the Montague H.S. unit also heats the junior high school. A similar arrangement in Souris heats the consolidated school there.

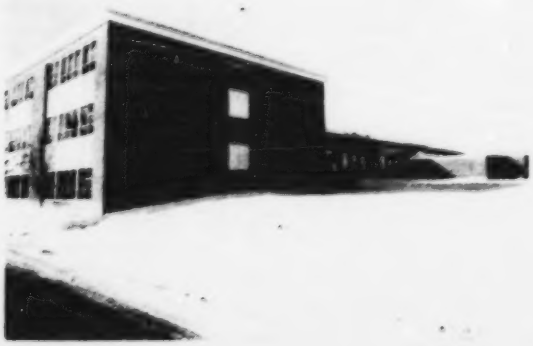
In the Charlottetown area, the schools heated by wood are U.P.E.I., Holland College Royalty Centre, and Charlottetown Rural High School. The Holland College and Charlottetown Rural facilities are connected to the district heating system fed by the U.P.E.I. plant. Thus, all three schools actually get their heat from the combustion plant at U.P.E.I.

In Summerside, the heating system at Unit 2's Three Oaks High School was converted to burn wood chips in 1988.

At the west end of the Island are School Unit No. 1, and the unit that serves P.E.I.'s Acadian community—Unit No. 5. Since 1985, the Evangeline Education Centre, located in Abram's Village in Unit 5, has been heated by a prefabricated wood chip heating plant installed behind the Centre. This plant is owned by La Coopérative Forestière Ltée. which sells heat to the school.

Four schools in Unit 1 were converted to burn wood chips in 1988: Westisle Composite High School, Hernewood Junior High, M.E. Callaghan Junior High, and O'Leary Elementary. The plant in the O'Leary school also heats the O'Leary Hospital.

Morell High School



Montague Sr. High School

Souris High School

Evangeline Education Centre

Charlottetown Rural High School

Westisle Composite High School

Three Oaks High School

All of the school boilers are designed to burn whole-tree wood chips, and the newest systems are also able to burn processed sawmill residue. All systems are fully automated. No additional staff is required beyond that needed for oil-fired systems. The maximum output of the combustion units varies from location to location, ranging from less than 300 kW, to 800 kW. The original oil-fired boilers have been kept for emergency use, and are also used to supply extra heat during extremely cold weather.

Wayne Hooper was business superintendent of Unit No. 4 when it acquired its first wood chip systems. He is a firm supporter of wood heat in the schools: "The savings from using less-expensive energy can be applied to other areas that have a more direct effect on the students. This technology also benefits the community. It creates jobs, and keeps money spent on energy in the community."

EXPERIMENT

Heat Output and Wood Moisture Content

Introduction

A given mass of dry wood fibre has approximately the same energy content regardless of tree species. But only so-called "oven dried" wood is 100 per cent dry fibre. Most wood is part dry fibre and part water. For example, as much as half the mass of "green" wood—wood that has just been cut—may be water. The water content is lower—perhaps only 20 per cent—in wood that has been sitting for months in protected piles. Wood stored indoors may have even less than that: the table in Chapter 5 refers to wood with 10 per cent moisture content.

Burning green wood in residential wood stoves is difficult to do, and is poor practice anyway because of the large amount of soot and creosote it generates. This is not the case with large chip-burning installations. These systems are designed to burn green wood as easily as dry. Nevertheless, burning green wood still exacts a price: part of the wood's energy is used just to vapourize the moisture and drive it off. That energy is not then available for useful heating.

Materials

A piece of freshly cut "green wood" having a mass of about 100 g, a piece of seasoned wood having a similar mass, a laboratory balance, and an oven.

Procedure

Using the balance, accurately determine the mass of each piece of wood. Then bake both pieces in a 115°C (240°F) oven for two hours to drive off all moisture. Let them cool; then check the mass of each piece again. (If it is not possible to do that immediately, wrap each cooled piece in plastic wrap and keep them wrapped until it is.)

1. Determine the original per cent moisture content of the green and seasoned wood.

2. Next, calculate the amount of energy required to drive the moisture out of each of the two pieces. The key to making this calculation is a factor called the *heat of vapourization* of water. *The heat of vapourization of a liquid is the quantity of heat energy that must be added to 1 gram of that liquid at its boiling point to change it into a gas or vapour.* For water, the heat of vapourization is 2.3×10^3 J/g.

3. Assume that the energy content of oven-dried wood fibre is 2.1×10^4 J/g. Calculate the percentage of the energy in each stick's wood fibre that would have been needed to drive off the moisture originally present in that stick.

4. Back in the section USING WATER TO STORE HEAT, the sample problem assumed wood having 10 per cent moisture content. No adjustment was made, however, for the energy required to vapourize that moisture. What per cent error did this introduce in the answer to that problem?

5. At some level of moisture content, all the wood-fibre energy in a piece of wood would be needed just to vapourize the wood's moisture. What percentage moisture would this be?

"Wet wood doesn't burn well"

Garbage Incineration

In February 1983, garbage began to flow into P.E.I.'s Energy-From-Waste plant in Parkdale, and steam began to flow out. Now, more than 30 000 tonnes (30 million kg) of garbage are burned in this facility each year, and as much as 35 million kilograms of steam are delivered to the Queen Elizabeth and Hillsborough hospitals. As a result, an annual three million litres of imported oil need not be purchased. At the current cost of fuel oil, how much is this worth?

Getting energy from garbage does work. Today, almost all the burnable garbage from Charlottetown-area communities goes to the Energy-From-Waste plant instead of to landfill sites. What does end up in landfill sites is non-burnable trash, and the ash left over from the garbage combustion process. And that's not much. The ash volume is less than 10 per cent of the volume of the original garbage.

Low-Pollution Burning

Burning garbage in dumps, or in old-fashioned incinerators, was a smelly operation. In both situations, burning released much disagreeable material into the air. The performance of the Parkdale plant, however, is vastly different.

Stack emissions are low. Air pollution testing was carried out by Environment Canada when the plant first opened. Those initial tests showed ground-level

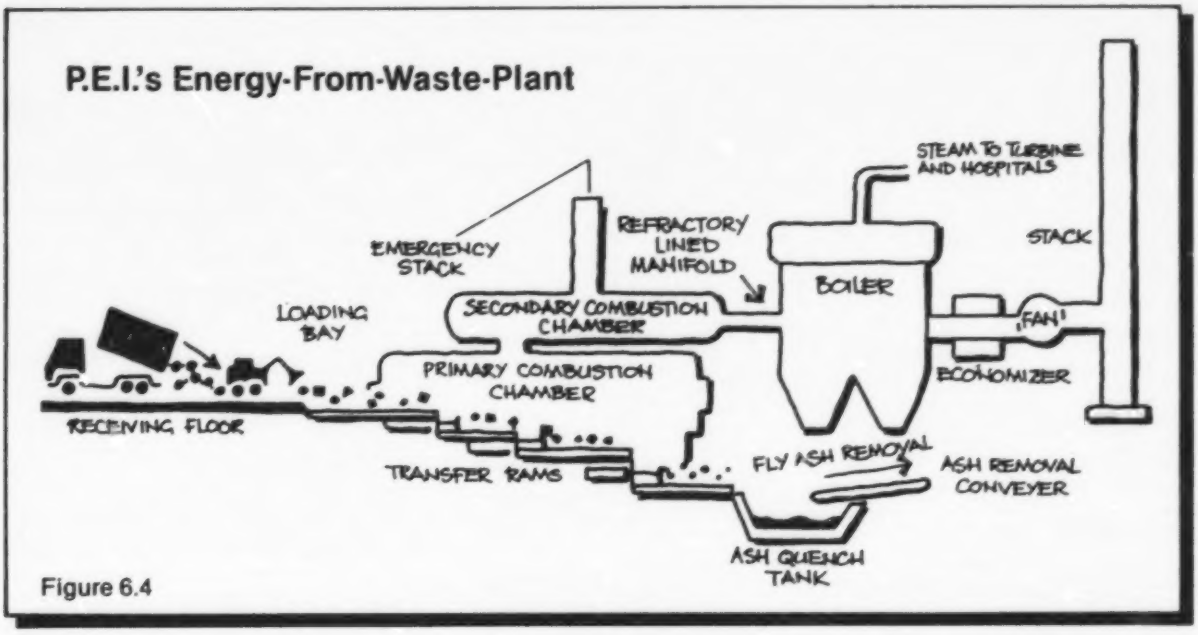


Figure 6.4

One reason for the low stack emissions from P.E.I.'s Energy-From-Waste Plant is the extremely hot, two-stage combustion process.

particulate concentrations at only ¼ the provincial standard of 100 micrograms per cubic meter. More comprehensive tests were run in December 1984 as part of the National Incinerator Testing and Evaluation Program (NITEP). Emissions of organic substances and heavy metals were measured and found to be well within federal guidelines. In fact, the NITEP used the term "excellent" to characterize the plant's overall test results.

The plant's extremely hot, two-stage combustion process is the reason that stack emissions are low. As Figure 6.4 indicates, there are two long combustion chambers. The garbage is fed into the first, and is burned there. As newly introduced garbage is heated, combustible gases are released. These gases are burned in the second chamber. The temperature in the first chamber is 620 to 720 degrees C, and in the second, 1000 degrees.

The fully burned 1000°C gases pass through a boiler where they generate steam—up to 6800 kg of steam per hour at a pressure of 3000 kPa. In passing through the boiler and the heat-extracting "economizer," these gases cool to 220°C, then pass up the stack. The steam generated by the plant passes through a turbine that generates electricity for the plant. It then travels through an insulated steam line along Riverside Drive to the two hospitals.

Energy-From-Waste Plant, Parkdale.

CHAPTER 7

THE BIOMASS OPTION

Biomass Energy Distribution Systems

Combustion turns a fuel's chemical energy into intense, high temperature heat energy. In most cases, however, that heat is needed somewhere else. Almost always, some sort of *heat distribution system* must be used to move heat from the combustion chamber to the place where the heat is required.

Heat Distribution Within Buildings

The Wood Stove

In the simplest situation—where a room or small building is heated by a wood stove—the distribution system is both simple and complex. It is simple in the sense that not much equipment is involved. But it is complex in that all three of the basic heat transfer mechanisms come into play: *conduction, radiation,* and *convection.*

Many wood stoves consist of little more than a cast iron or steel combustion chamber set on legs. The metal walls conduct heat from the fire inside to the chamber's outside surface. Heat energy radiates outward from this surface in the same way that light energy radiates outward from the white-hot filament of a light bulb. Stove walls occasionally get hot enough to give off light—and then we say that the stove is red hot. Usually, however, all the radiation occurs outside the *visible* portion of the electromagnetic spectrum—that narrow range of wavelengths (0.4 to 0.7 millionths of a metre) to which the human eye responds. Radiation from a wood stove normally occurs in the *infra-red* range of wavelengths, betweeen 0.7 and 300 millionths of a metre.

This radiant infra-red energy travels with the speed of light in all directions. It strikes the room's walls, floors, and human skin, and is absorbed by them—causing the temperature of these materials to rise.

This direct, electromagnetic radiation of infra-red energy to nearby surfaces is why wood stoves must be spaced well away from combustible materials. It is also

Convection Air Currents

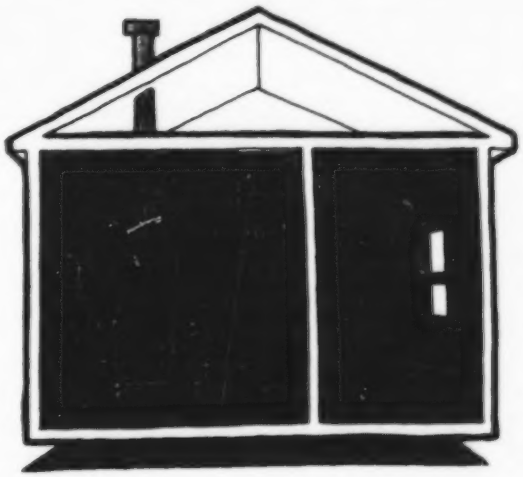


Figure 7.1

A hot wood stove sets up convection air currents. If the stove and the vents between rooms are carefully placed, a stove in one room will supply some heat to other rooms. But with this simplest of heat distribution schemes, it's hard to get even heating.

the reason why an outdoor stove or bonfire warms you on a winter day even though the temperature of the air between you and the heat source is well below freezing.

In our wood stove example, the second way in which heat is distributed is by air *convection.* Not only do the surfaces of the hot stove radiate energy, they also increase the temperature of the immediately adjacent air. This warm air then rises, and is replaced by cooler air. As Figure 7.1 illustrates, the hot stove sets up convection currents. If the stove and the vents between rooms are carefully placed, a stove in one room will supply some heat to other rooms. But with this simplest of heat distribution schemes, it's hard to get even heating. Especially if the house is not well insulated, the room with the heater is apt to be warmer than desired, and the other rooms colder.

Electromagnetic Radiation:

The Fast-As-Light Form of Energy

Light and radiant heat (infra-red) energy are just two of the many varieties of electromagnetic energy. Others are radio waves, microwaves, ultra-violet rays, x-rays, and gamma rays. In ordinary conversation we distinguish one from another by the effects they produce and the uses to which we humans put them. But in a purely physical sense they are all electromagnetic energy. One variety differs from the next only in wavelength and frequency of vibration. On the keyboard of electromagnetic radiation, radio waves are the low notes; infra-red, visible light, and ultraviolet fall in the middle; and x-rays and gamma rays are the high notes.

The table below shows the wavelength in metres and the frequency of vibration for each type or variety of radiation. All varieties travel at the velocity of light: 3.0×10^8 m/s. Frequency equals the velocity of light divided by wavelength.

Variety	**Wavelength** (in metres)	**Frequency** (in Hertz)
Radio waves (VLF thru UHF)	3.0×10^{4} to 3.0×10^{-1}	1.0×10^{4} to 1.0×10^{9}
Microwaves	3.0×10^{-1} to 3.0×10^{-4}	1.0×10^{9} to 1.0×10^{12}
Infra-red rays	3.0×10^{-4} to 7.0×10^{-7}	1.0×10^{12} to 4.3×10^{14}
Visible light	7.0×10^{-7} to 4.0×10^{-7}	4.3×10^{14} to 7.5×10^{14}
Ultraviolet rays	4.0×10^{-7} to 10^{-9}	7.5×10^{14} to 10^{17}
X-rays	10^{-9} to 10^{-11}	10^{17} to 10^{19}
Gamma rays	shorter than 10^{-11}	higher than 10^{19}

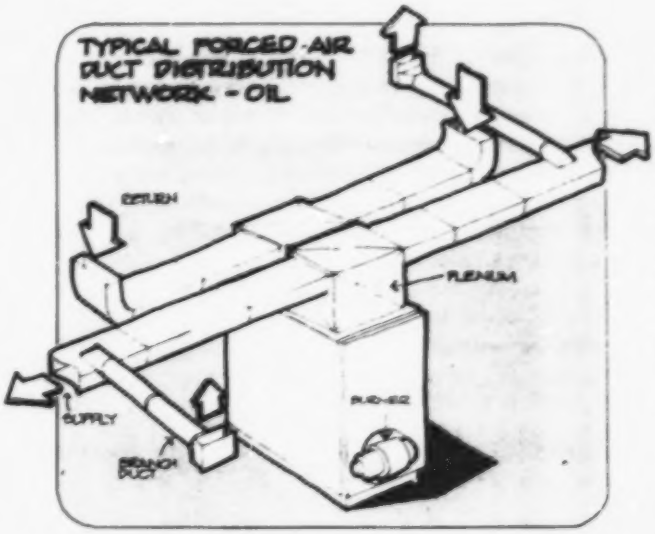
Problems

1. Charlottetown radio station CFCY radiates 10 000 watts of electromagnetic power on a frequency of 630 kilohertz (630 000 cycles per second). What is the wavelength of the radiated energy?

2. Helium-Neon lasers (the kind used in supermarket checkout scanners) emit light energy in the red region of the visible spectrum at a wavelength of 6.328×10^{-7}m. What is the frequency of this light energy?

Forced-Air Heat Distribution

Much more uniform distribution of heat can be achieved in forced-air systems. In these systems a furnace is used—one that efficiently transfers combustion heat to moving air. A blower or fan causes air to flow across the furnace's heat transfer surfaces. This warmed air then travels through hot air ducts to distant parts of the building. Cool, floor-level air returns to the furnace through cold air ducts. Because the air is forced to circulate, the temperature throughout the building is much more uniform than in our wood stove example.

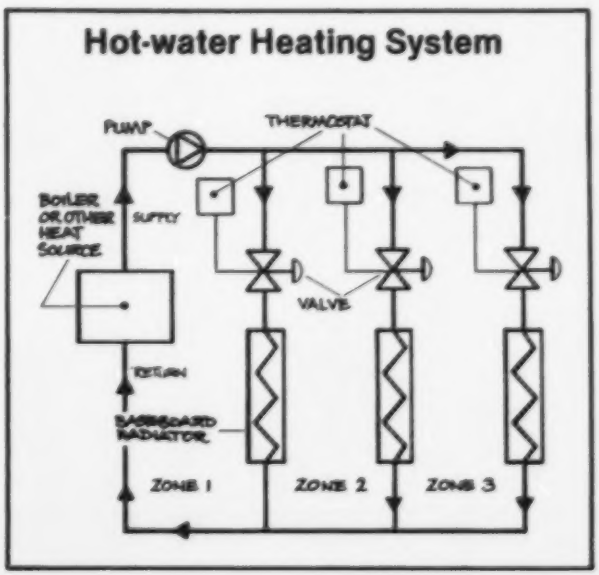


One feature of forced-air heat distribution is that air from all over the building is brought back (via the cold air ducts) to one central location: the furnace. Because of this, it is possible to process the air in various ways:

- If a filter is put in this central air path, dust can be removed from the air.
- If moisture is introduced here, humidified air spreads evenly throughout the building.
- Outdoor air can also be introduced here—to "freshen" the building air without creating drafts.

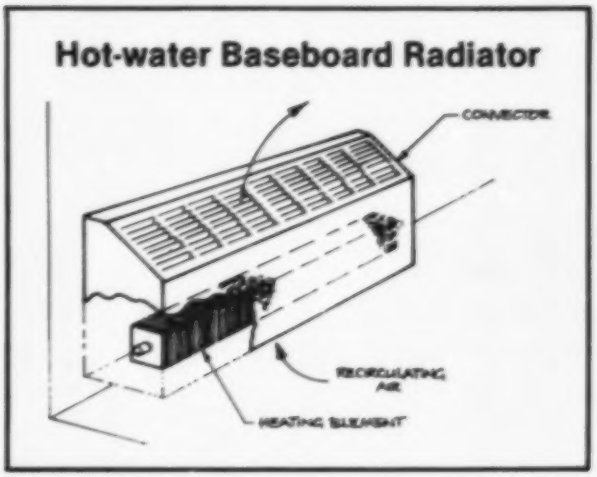
Hot Water Heat Distribution

Forced-air distribution also has disadvantages. Air ducts take up a lot of space in basements, and are expensive to install in the walls of existing buildings. Then too, hot air furnaces tend to be bulkier than hot water boilers. Consequently, hot water has become the favored heat distribution medium in recent years. In this type of distribution system, heated water flows through small, easy-to-install copper pipes—and its rate of flow can be easily controlled.

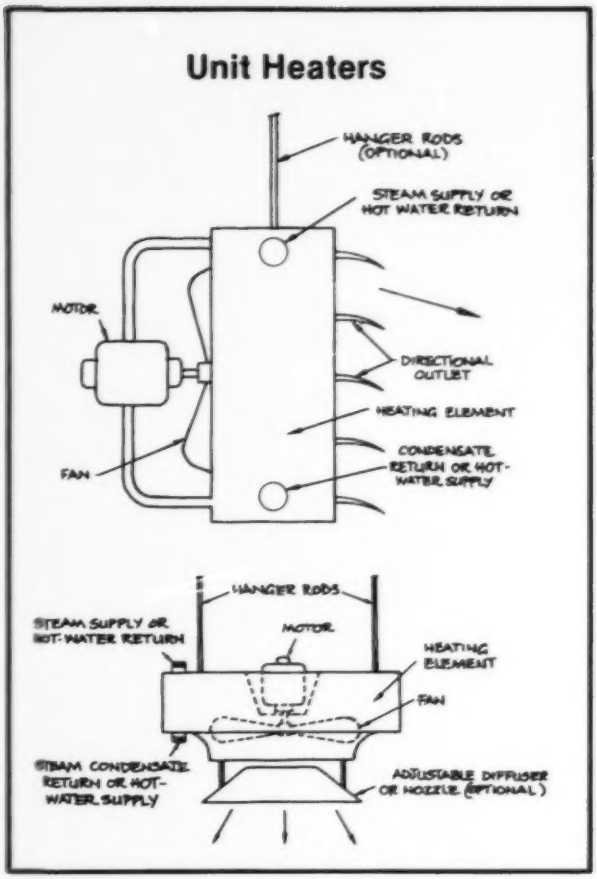


The hot water heat distribution systems used in homes are usually quite simple. Typically, one small electrically operated pump circulates and recirculates a small amount of hot water through the boiler, through baseboard radiators in each room, and back to the boiler again. Usually, the boiler heats the water to a temperture of about 80°C.

A baseboard radiator is a length of pipe with metal fins attached, hidden behind a decorative metal cover. Because the fins conduct heat readily, they get hot, and because they have a large surface area, they warm the adjacent air. This heated air rises, and convection currents become established in the room. Generally, lengths of baseboard radiator are installed on the outside walls of a room, preferably under windows. When this is done, convection currents keep the temperature in all areas of the room fairly uniform.



In many commercial and industrial buildings, hot water from the boiler is also used to heat forced air. One type of device that does this is called a unit heater. It looks much like an automobile radiator with a fan mounted on it. Hot water circulates through its tubes, and the fan blows air across fins attached to the tubes. Buildings with ventilation systems often have other radiator-like devices installed inside duct work to preheat ventilation air.



In these unit heaters, hot water from a boiler is used to heat forced air.

As mentioned in Chapter 6, some roundwood-fired boiler systems use insulated tanks of water to store heat. Unlike oil- or propane-fired boilers, heat production in these boilers can't be turned on and off instantly. As a result, more heat is sometimes generated than the building currently needs. Water provides a convenient medium for storing this extra heat. In some systems the water tank is very large, and only one or two loads of wood need be burned each day. In some others, the boiler itself holds a large amount of water.

In these wood-boiler systems the stored hot water is circulated through standard baseboard radiators under thermostatic control. When the room gets cold, the circulation pump comes on and water from the tank moves through the radiators. When the room warms up, the pump goes off.

District Heating

The Concept

The idea behind urban district heating is simple: instead of putting a separate furnace or boiler in each building, use large centrally-located boilers to heat many buildings.

A district heating system has two basic elements: a heat source and a distribution system. The heat source selected will depend on local circumstances. There are district heating systems which use coal, oil, and gas-fired boilers; garbage incinerators; wood-chip fired boilers; nuclear power plants; geothermal wells; and heat pumped from sewage or other sources. Here on P.E.I., wood chips and garbage are the fuels used.

The heat, whatever its source, is distributed through a network of insulated pipes. These pipes carry hot water or steam from the heat source to subscribers' buildings. If steam is used as the heat distribution medium, transmission is limited to a few kilometres from the source. When hot water is used, much longer runs are possible. In one Italian system, heat travels 106 km from source to market.

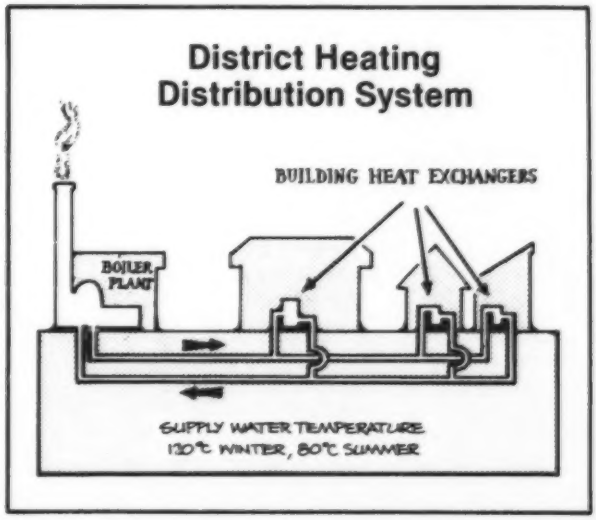
District heating carrier pipes are normally buried at depths ranging from 2/3 metre to 2 metres, ordinarily above existing underground service lines.

District Heating

An Old Idea Whose Time Has Come

District heating in North America dates back at least to 1877 when a system was installed in Lockport, New York. But this method of space heating never became commonplace here. In Europe after the Second World War, the situation was different. Urban areas grew rapidly, fuel costs were high, and (in some countries) whole cities had to be rebuilt. These factors made district heating economically attractive, and it soon became widespread there. In northern Europe—particularly Scandinavia—a sophisticated district heating technology developed. Today, almost all Scandinavian cities and many small towns have district heating systems.

Recently, this technology came to Canada—and P.E.I.'s district heating systems are among the first of these modern systems to be built here.

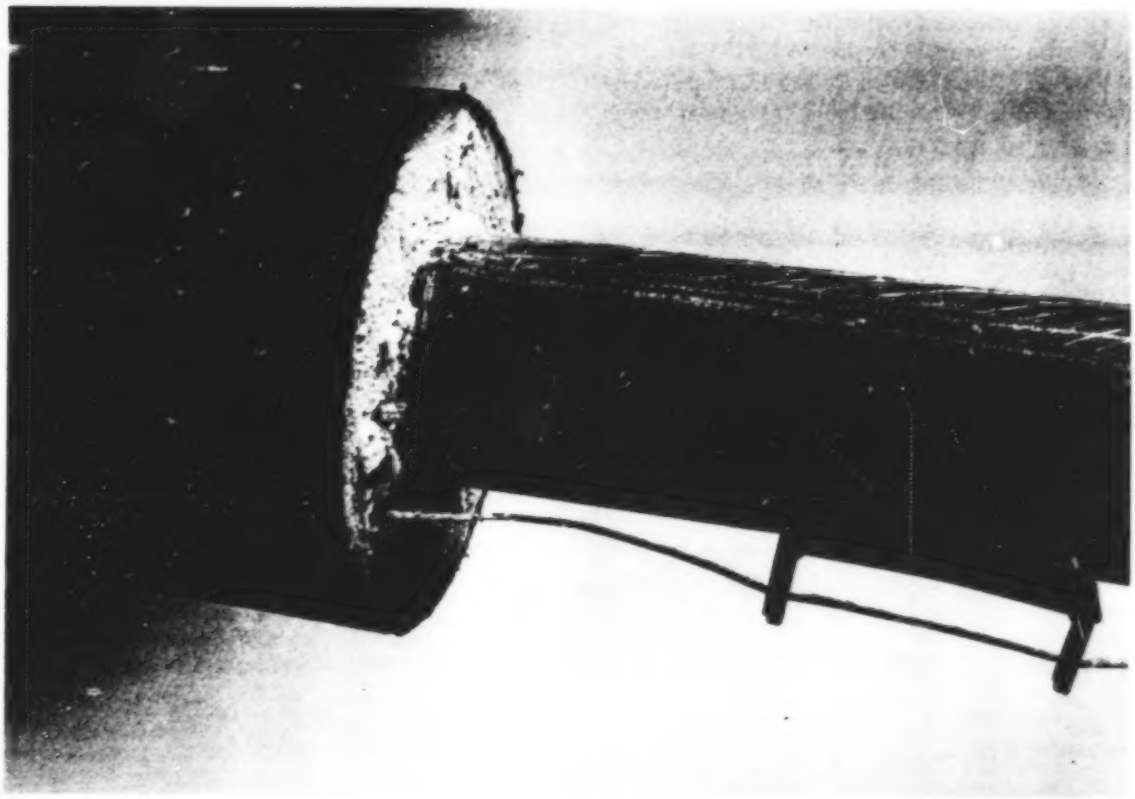


Island district heating system distributing heat from a central boiler plant to surrounding buildings through a network of buried insulated pipes. Hot water is the heat distribution medium.

At normal atmospheric pressure, water boils at 100°C. In systems designed for higher pressures, it's possible to raise the temperature of water above 100°C without it turning to steam. In DH (district heating) systems of recent design, water temperature from 80°C to as high as 120°C are common.

District heating distribution systems use parallel sets of pipes. The 80 to 120°C water coming from the heat generating plant is delivered by insulated *supply* pipes, and is returned to the plant (at a temperature some 40 to 60°C cooler) by insulated *return* pipes. The largest pipes in use on the Island are 20 cm in diameter; the smallest are 4 cm. They are carbon steel pipes, preinsulated with high density polyurethane foam. The insulation is covered with a molded polyethylene jacket. Carrier pipes are joined by arc welding, and the joints are then insulated with polyurethane foam. Pipes are buried at depths ranging from 2/3 metre to 2 metres, ordinarily above existing underground service lines.

In P.E.I.'s larger systems, an electronic leak detection system is used to detect breaks in the polyethylene jacket or carrier pipe. Moisture is sensed by measuring the electrical resistance between wires imbedded in the pipe insulation. If the insulation is dry, the electrical resistance between wires is high; if wet, the resistance drops dramatically. Once damp insulation is detected, its location can be pinpointed—usually within one metre—by sending electrical pulses down the sensing wires, and measuring the time it takes the pulse to return from the point of reflection (the wet insulation.)



Typical district heating carrier pipe. Note the carbon steel pipe, the foam insulation with imbedded leak detection wires, and the outer polyethylene jacket.

There are other things, too, that must be taken into account in designing and maintaining a district heating system. First, provision must be made for pipe expansion and contraction. Because steel expands when heated, a district heating carrier pipe is slightly longer when it's hot than when it's cool. This changing length must be allowed for in the layout of the system; otherwise, pipes could break. Various technques are used including U-, L-, or Z-shaped bends in the pipe, and bellows-like length compensators.

Second, DH distribution water requires special treatment. The larger P.E.I. systems have been filled with partially demineralized water to prevent the buildup of mineral deposits on the inside walls of the pipe. Pipe corrosion is prevented by using steam deaeration to remove oxygen from the water, and by adding sufficient sodium hydroxide (NaOH) to make the water alkaline, with a pH of 10.0.

Heat losses in well-designed systems are small—generally under 10 per cent, and frequently under five per cent. This contrasts with the early district heating systems which used steam to distribute the heat. Losses in these systems were typically 40 per cent.

The Subscriber Connection

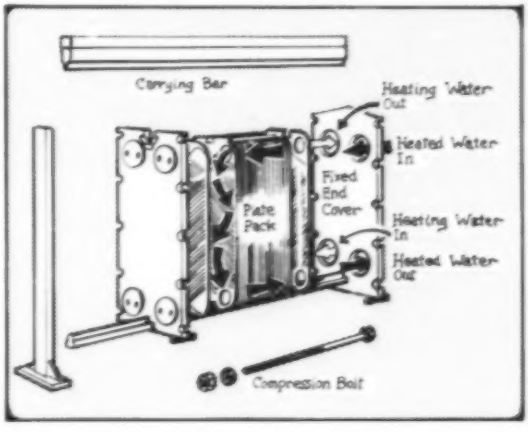
In most district heating systems the high-temperature, pressurized, distribution water does not circulate directly through radiators in subscriber buildings. It flows instead through a *heat exchanger*, a device which transfers heat from the distribution water to the building's own heating system water, while keeping the two systems separate.

As we've seen, the heat distribution systems in most modern buildings raise the temperature of the space by circulating hot water through radiators and unit heaters. This sort of system is very easy to convert to district heating; a heat exchanger simply replaces the hot water boiler. Heat exchangers allow the district heating water to be sent to subscribers under elevated pressure at temperatures above the normal boiling point of water (100°C), and they provide desirable isolation between the district heating system and the building's own heat distribution system. The use of heat exchangers allows subscribers to decide what their own in-building flow rates and pressures will be, and they can modify their systems without involving the heating utility.

Each building served has at least two heat exchangers. One transfers heat to the building's internal piping and radiator system. The other heats domestic hot water (DHW)—the hot water you use for dishes and baths. Sometimes there is a third exchanger which is used for special purposes such as preheating ventilation air, or heating swimming pool water. At each subscriber location there is also a meter to measure the amount of heat consumed by that facility.

Different heat exchanger designs accomplish this heat transfer in different ways. In Island district heating systems, two types are used: flat plate and coil. Flat plate units are used where much energy must be transferred: at the interface between a steam boiler and the DH distribution system, for example, and at the interface between the system and very large subscribers. In this type of unit the two fluids—boiler steam and DH water, for example—are separated by thin, large-area metal plates. The low thermal resistance of this design allows a physically compact unit to transfer a lot of heat.

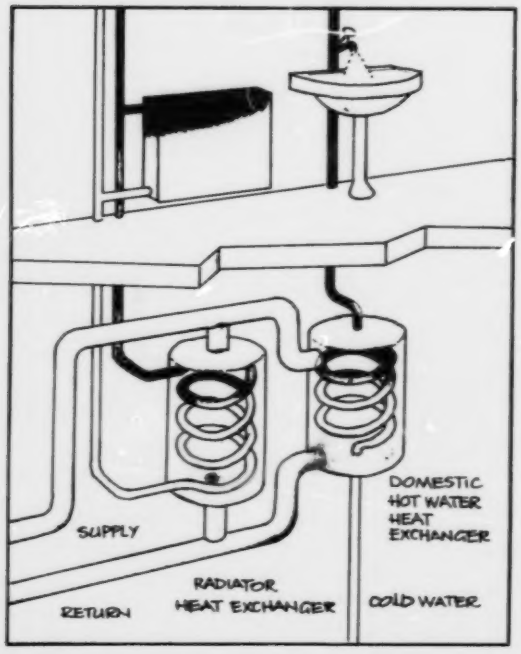
Flat Plate Heat Exchanger



In the flat-plate type of heat exchanger, thin metal plates separate the two fluids involved. Because the plate area is large, much heat can be transferred with little temperature drop in a physically compact unit.

Coil-type heat exchangers are used in all other situations. Here, a copper coil is housed within a steel pressure vessel. DH water circulates through the pressure vessel while subscriber water circulates through the copper coil. Heat easily passes through the copper, but building water is kept separate from DH water.

Coil-type Heat Exchanger



Coil-type heat exchangers provide desirable isolation between the district heating system and the building's own heat and domestic hot water distribution systems.

A typical building hookup is shown in Figure 7.2. Building space temperature is maintained by two control systems, one on the DH side of the heat exchanger, one on the building side. On the district heating side, a controller (programmed by outside air temperature) changes the rate of DH water flow to maintain a suitable temperature on the building side of the heat exchanger. On the building side, the flow of hot water in the building's hot water radiator system is turned on and off by room thermostats.

A controller keeps the domestic hot water temperature at 55°C by adjusting the flow of district heating water through the DHW heat exchanger.

District Heating Subscriber Substation

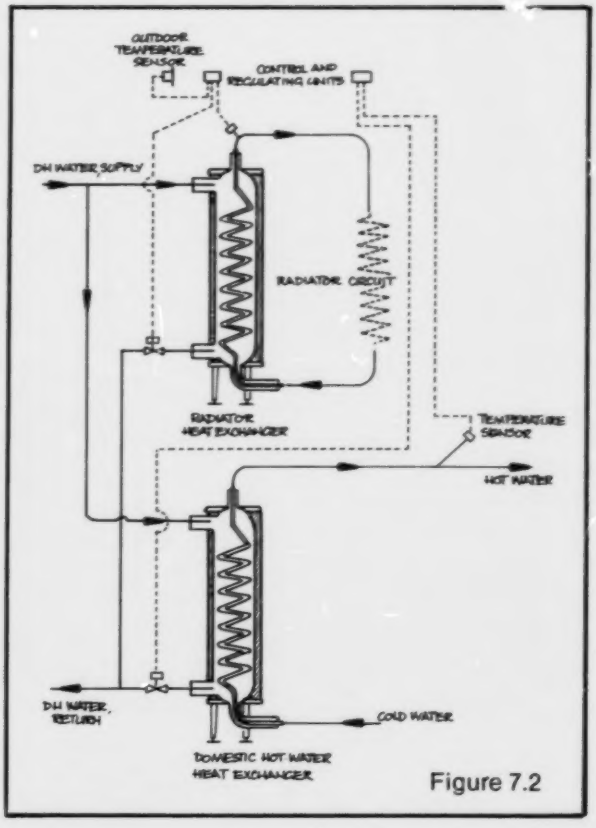


Figure 7.2

Each building served by a district heating system has at least two heat exchangers. One transfers heat to the building's piping and radiator system. The other heats domestic hot water—the water used for dishes and baths.

Metering Heat

If you heat with oil, you pay for a measured number of litres poured into your tank from the oil truck. If you buy roundwood for heating, you pay for a measured number of cords delivered to your yard. Oil and wood are easily measured. But what happens if your building is attached to a district heating system? Then the commodity is not a physical liquid or solid, but heat itself. How do you go about measuring that? How would you measure the amount of heat energy consumed by a building?

The principle behind heat metering is actually quite simple, but practical meters had to await the arrival of modern electronics. The basic idea is to sense the water temperature as it enters the heat exchangers from the DH system *supply* pipe, sense the temperature of the water returning to the DH system *return* pipe, and measure the rate of flow of DH water through the heat exchangers. If there is no temperature difference, no heat is being consumed. If there is a temperature difference, and if the rate of flow is known, then the heat consumption can be calculated.

The heat meters used in P.E.I. systems continuously monitor the two temperatures and the flow rate. Using that data, and the specific heat capacity of water, these meters electronically calculate the heat consumed and update an odometer-style totalizer.

Have you grasped the concept?

Picture a building connected to a district heating system, and solve this problem:

The totalizer in the building's heat meter shows the accumulated heat consumption in kilowatt-hours. The DH water temperature going into the heat exchangers is 100°C. The temperature of the water coming out of the heat exchangers is 60°C. The flow rate is 1.0 litre per second. How many seconds will elapse before the building consumes another kWh of heat energy and the meter indicates a one digit higher reading?

District Heating on the Island

Although Prince Edward Island does not yet have the sort of city-wide district heating systems that are common in Scandinavia, we are moving in that direction. We already have two small multi-subscriber systems in the Charlottetown area, and are talking about interconnecting and expanding them. Both of these systems use the latest Scandinavian technology: preinsulated steel pipe, electronic leak detection, building heat exchangers, and heat meters.

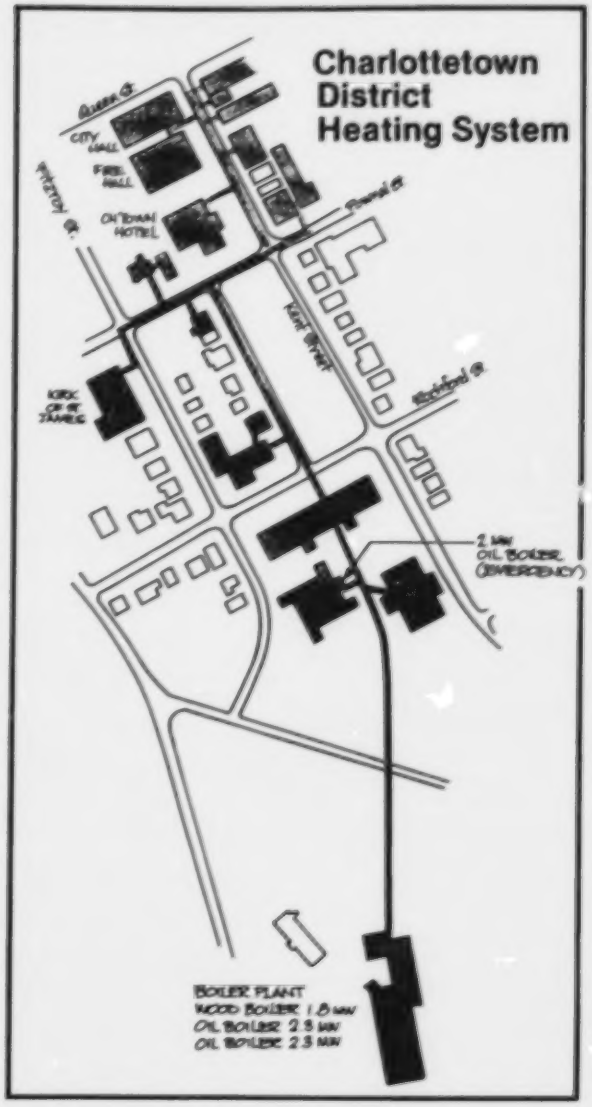
The Downtown Charlottetown System

Downtown Charlottetown's Small-Scale District Heating System began as a project to heat the provincial government buildings and a senior citizen's home. In the end it became a small district heating system, providing heat not only to those buildings, but to 13 others also. This small-scale district heating system was the first in Canada to use modern European district heating technology in combination with low cost, locally available wood chip fuel.

The heat source in this system is a 1.8 MW wood-chip fueled boiler housed in the boiler room of the Prince Edward Home for the Aged. Under most conditions it generates all the heat required. The two original 2.3 MW oil-fired boilers, plus a 2 MW oil-fired unit in the provincial administration buildings, serve as backup and generate the additional heat needed to meet peak heating loads on the coldest days.

The wood-chip boiler at maximum output supplies one third of the system's peak heat demand of 5.3 MW. It also supplies 75 per cent of the total heat energy consumed by the system during a year. In doing this, it consumes 4500 green tonnes per year of whole-tree chips, and so 1.2 million litres of oil don't have to be purchased.

A 250-metre-long buried insulated pipe system carries 80-to-120°C pressurized hot water from heat exchangers at the boiler site to the provincial government buildings on Rochford Street. From there the pipe network goes on to City Hall, a distance of 712 metres. Along the way short branch lines deliver heat to St. Peter's Cathedral, the Kirk of St. James, the Charlottetown hotel, the Fire Hall, The Dundee Arms Inn, the Islander Motor Lodge, and six other buildings. A return pipe carries hot water back to the boiler along the same route. Heat exchangers in each building transfer the heat to that building's heat distribution system.



The main supply and return lines are 125 mm diameter. All lines are insulated with high density polyurethane foam, and the insulation is protected by a polyethylene jacket. The substations in subscriber buildings use coil type heat exchangers except for those in the provincial administration building complex which are of the flat plate type.

This DH system benefits those connected to it in various ways. For one thing, subscribers pay less for heat than they used to. While most of the money saved on fuel goes toward the capital cost of the system, some is passed on to the users. It works this way: the

heat delivered to each building is metered. Bills are based on the amount of heat used, and on each facility's peak demand for heat. The rates have been set to make the average annual heating cost slightly less than the cost of heating with oil. Other advantages include freed-up space when the old boiler is removed, lower heating system maintenance costs, and, in some cases, even reduced insurance rates.

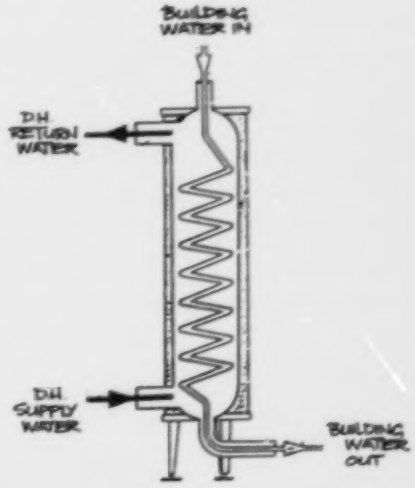
The present Charlottetown system was designed so that it can interconnect with a future large-scale district heating system. The business community seems interested in expansion, and—if conditions are favorable—much of the city may some day be heated this way.

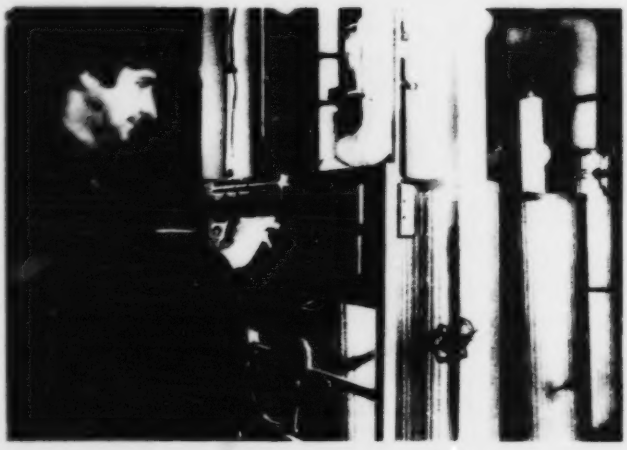
Georgetown Shipyard Makes Heat Exchangers

The Island's largest district heating systems are patterned after the systems that have proven so successful in Sweden and other Scandinavian countries. In fact, many of the components used in our systems were made in Denmark, Finland, and Sweden.

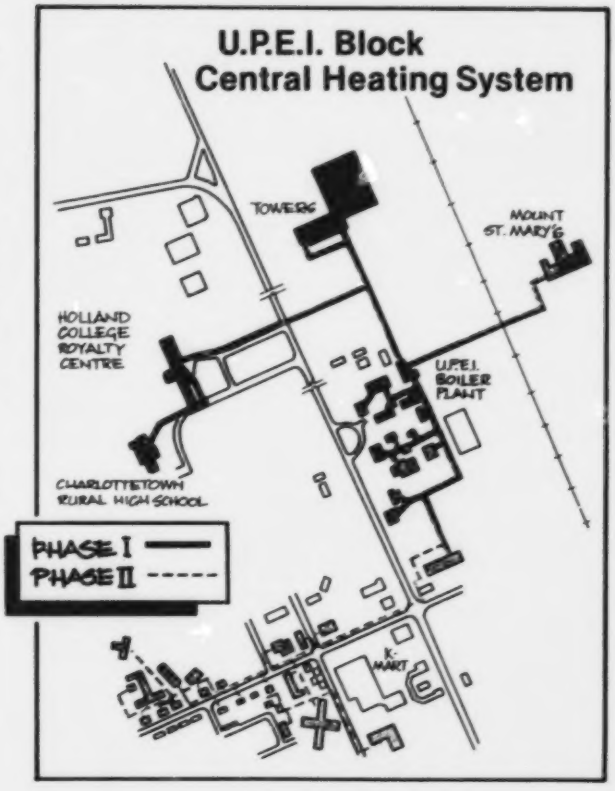
Key components, the coil-type heat exchangers used in subscriber buildings, are an interesting exception. They were designed in Sweden, but are built right here on P.E.I. at Georgetown Shipyards.

The arrangement seems a good deal for everyone involved. Our boiler inspection code required that the heat exchangers be built in an approved facility. Georgetown Shipyards had the necessary approval, and while there were also approved facilities in Europe, it would have been much more expensive to have the heat exchangers built there. Consequently, the Elge company of Linkoping, Sweden, arranged to have the work done here. This arrangement resulted in manufacturing work for Islanders, less expense for the P.E.I. Energy Corporation (the builder of our district heating systems), and a North American-based manufacturing capability for Elge.





Whole truckloads of wood chips can be dumped into the U.P.E.I. boiler plant chip storage bin.



The U.P.E.I. System

This system delivers heat to 31 subscribers in areas of Charlottetown, West Royalty, and Sherwood located near the University of Prince Edward Island. The system carries heat from U.P.E.I.'s wood-fired heating plant north to Holland College Royalty Centre, Mount St. Mary's, and the Charlottetown Mall, and south to the Belvedere Avenue area. The total plant output is 13.7 megawatts, enough to heat the campus and the 31 subscriber buildings.

The main heat distribution lines are shown on the map. Hot water from the U.P.E.I. boiler plant travels along each route through a buried 200-mm diameter insulated pipe. Water returns to the boiler through a second, parallel, insulated pipe. In all, 6 km of pipe have been laid.

Co-Generation of Heat and Electricity

Many people are not aware that generating electricity by burning fuel—any fuel—is an inefficient proposition. Only 25 to 35 per cent of the energy in the fuel ends up as electrical energy. The remainder becomes medium temperature heat energy, which, in the usual electrical plant, is discharged to the environment and wasted.

The idea behind co-generation is to use that "waste" heat for some useful purpose such as industrial process heating or building space heating. In these co-generation systems, almost the same percentage of fuel energy still ends up as electricity, but much less of the remaining energy is wasted. From 60 to as much as 90 per cent of the fuel's energy ends up doing *something* useful. Feeding that waste heat into a district heating system is one possible use for it.

Co-generation techniques vary from situation to situation. In some small generating plants, diesel engines drive electric generators. Here, exhaust gases and the water which cools the engine can be used for heating.

In large plants, fuel-fired boilers generate steam which flows through turbines, and these turbines drive electrical generators. In one common arrangement, the spent steam leaving the turbines is passed through a heat exchanger. There it condenses and releases heat—heat that raises the temperature of the district heating system's supply water.

Co-Generation and Energy Quality

Electrical energy and high-temperature heat energy are both *high-quality* forms of energy. You can do a lot with them, use them for many purposes. As high-temperature, high-pressure steam passes through a turbine, some of its energy goes the high quality route. It is converted into the mechanical energy of turbine rotation, and then to electrical energy. In the process, however, the steam loses both temperature and pressure—and the energy in the remaining steam is degraded in quality.

You will recall the second law of thermodynamics: *In most energy interchanges, there is a decrease in the amount of energy available to do useful work.* This is what has happened here. The total amount of energy in this residual steam is still considerable, but it's no longer *versatile* energy. There are fewer things you can do with it. So few things, in fact, that most electrical generating plants throw their residual steam away even though it contains more than half of the original energy!

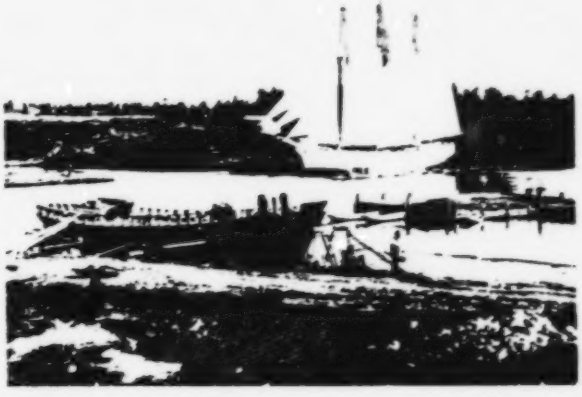
Many people are convinced that we can no longer afford such waste. We must think more holistically, they say. We must try to arrange things so that this low quality "waste" energy performs tasks that we would otherwise use high quality energy to perform. Heating the space within buildings is one of these uses, and the district heating type of distribution system is a practical way to get the heat from a central electrical plant to buildings that need it.

CHAPTER 8

THE BIOMASS OPTION

The Future of Biomass Energy

Is biomass energy an option that makes sense for Prince Edward Island, now and in the future? Does using wood for energy hurt our forests or help them? What level of long-term energy demand can our forests sustain? Regarding atmospheric pollution, how does wood compare with other fuels? This last chapter will deal with these questions and others. It will examine the effect of biomass energy activities on the forest resource and the environment, and will look at some possible directions which biomass energy might take in the future.



The schooner, The Empress — one of many from the Montague River.

Wood Resource Management

The Forest Resource

When the first European settlers arrived here, almost all of the Island was covered by a mature, multi-species forest sometimes referred to as a *climax* forest. Beech, maple, and birch appear to have been the primary hardwood species, but there were also oak, ash, elm, and poplar. White pine, hemlock, white cedar, fir, larch, and spruce were the major softwoods. Early reports referred to the size of the trees—large-diameter birch and hemlock, and the many white pine two feet or more in diameter.

The settlers cut trees to build houses. They cleared land for farming. And, during the 1700s, several fires destroyed large tracts of forest. But the real trouble for our forests arose in the early 1800s when Britain (engaged in a war with France) turned to her North American colonies for timber, and ships built of timber. Accounts indicate that between 1806 and 1866, close to 3000 ships were built on P.E.I. and many thousands of loads of lumber were shipped to Britain. During the mid-1800s there were over 140 sawmills operating in the province. Both the number of ships built and the number of operating sawmills fell in the late 1800s as the availability of large trees declined.

In his book, *Forestry Past and Present on Prince Edward Island,* J. Frank Gaudet said:

> The shipbuilding industry took the best of all species. The straightest, tallest and best quality trees fell to the lumberman's axe.... The best beech, ash, oak, maple, birch, pine, red spruce, larch and cedar were taken, sometimes to the extent of almost completely ridding the province of these species. The

crooked, knotty, limby trees could not be utilized so they provided the seed source for the next generation of trees.

Tree Genetics and the State of Our Woodlots

Many of the physical differences between one person and another, one cat and another, and one white pine and another result from differences in the mix of *genes* which the individual inherited. Biologists look at an entire species and speak of a diverse *pool* of genetic material spread throughout the species. There are genes for height (tall and short), genes for colour (light and dark), etc., and each individual inherits a specific mix of genes drawn from the *gene pool* of that species. Genes are passed from generation to generation via whatever process of reproduction that species uses.

Most species of trees are bisexual, producing both pollen and ovules. In a few species (such as ash) there are male trees that produce pollen but no ovules, and female trees that produce ovules but no pollen. In most species, airborne pollen from other trees is what fertilizes the ovule. The fertilized ovule becomes a seed, and that seed contains the complete genetic blueprint for growing a new tree. Part of the plan came from the tree bearing the ovule, and part from the tree that produced the pollen.

With that process in mind, it's not hard to imagine the bad effect on the gene pool of

consistently removing the tallest, straightest, largest-diameter trees—year after year for a couple of hundred years. What remained would be a lot of genes for short, twisted, and thin trees, but few genes for tall, straight, and large diameter trees.

Because the growing of trees is so climate dependent, and so soil dependent, bringing seeds to P.E.I. from distant places is not an ideal solution. The approach here has been to scour our own woods for those rare high-quality "Plus" trees that still have the right genetic stuff, and take cones or cuttings from them.

The gathered material is used, under controlled conditions in a nursery, to produce genetically superior seed. The process takes many years, but new seed is eventually generated, and seedlings are grown from this seed. These seedlings are then planted on land that has been harvested, that is, cleared of poor quality trees. Under the 1988-1993 Forest Resource Development Agreement, over 10 million of these high quality seedlings will be produced and planted.

During the first half of the present century, much farmland—amounting to about ¼ of P.E.I.'s total land area—was abandoned. The two world wars, the Great Depression of the 1930s, and the lure of cities and jobs elsewhere were all contributing factors. Natural seeding processes caused trees to grow on this abandoned land, but the resulting woodlots were generally of inferior species and quality. The seed, in most cases, had come from second-rate trees in the windbreaks between fields. Some of these were fine trees for windbreaks—bushy, branchy trees—but trees not destined to produce sawlogs.

Some sawmills continued to operate during this period, but the number of trees suitable for cutting into lumber continued to decline. That unfortunate attitude, "Cut the best and leave the rest," was still commonplace. There were (and still are) some sawlogs to be found in Island woodlots, but they amounted then (and amount today) to only a small percentage of the total biomass.

Concern about the poor state of our forests arose in the late 1930s, and in 1952 a $25 000 per year reforestation effort began. Concern continued to grow through the '60s and '70s, and, slowly, so did the amount of money committed to the forest improvement task.

Then, in 1983, the federal and provincial governments set up a five-year $20 million forest resource development program. More than 2000 Island woodlot owners became involved in this program. With the help of government forest technicians, woodlot owners developed forest management plans for their woodlots, and agreed to implement these plans. The first five-year federal/provincial agreement was followed in 1988 by a second—this one involving $24.1 million.

Forestry program activities were put into a long-term context in 1986 when the provincial government originated a *Twenty-Year Forest Development Plan* which discussed strategies for restoring our forests to a healthy and productive state. The next year the province issued a *Forest Policy* based on the *Plan* and on input from the public. In this policy statement the government said that its "...first priority will be to restore and improve the productive forest base."

The 1988-1993 federal/provincial forestry agreement has many aspects. They range from exploring new market opportunities, to raising public awareness, to growing millions of quality seedlings. Those aspects of particular concern to us here, however, are the ones in which biomass energy plays a role.

Hardwood Fuelwood

As mentioned in Chapter 5, many Islanders burn roundwood to heat their homes, and they have a strong preference for hardwood. About 75 per cent of the roundwood burned is hardwood. An assesment of the forest resource in the mid-1980s revealed that while there was no apparent shortage of hardwood forest on the Island, the availability of roundwood fuelwood from this hardwood resource was limited. Moreover, the assessment revealed that on woodlots available for cutting, hardwood was being cut faster than nature was growing it. To avoid an eventual shortage of hardwood, something had to be done.

The 1988-1993 Agreement addressed the issue by setting up programs to increase the production of sawlogs, veneer-quality hardwood, and hardwood fuelwood. The first of these is a hardwood silviculture program with the goal of increasing the total volume of hardwood growth by thinning 1600 hectares (ha) of hardwood stands over the five year period of the Agreement. Removing small trees from a stand enhances the growth of the remaining trees. Also, since most of the thinnings are marketable fuelwood, the thinned material helps to meet the temporary shortfall. The goal of a related program is to remove softwood from 400 ha of mixed hardwood/softwood stands, thereby converting these stands to hardwood only. Together, these actions should raise the sustainable hardwood harvest to 220 000 m^3 per year — the amount needed to meet the existing demand for hardwood sawlogs and fuelwood.

Other program activities designed to benefit the hardwood resource include:

1. Encouraging domestic hardwood users to switch to softwood fuel.
2. Conducting research into techniques for helping shade-tolerant hardwoods (such as sugar maple and yellow birch) to regenerate.
3. A public information and education program to help the general public gain a better understanding of forestry and forest management activities.

Softwood and Wood Chips

With softwood, we face a different problem. While large-diameter, straight, softwood logs for making lumber are not abundant, the softwood available for energy purposes far exceeds the current demand. This is especially true of the poorest softwood—the material that's used for making wood chips. Moreover, it turns out that substantially increasing the demand

planted with quality "Plus" seedlings—becoming, in time, new woodlots full of high-quality trees. This replacement activity would result in more sawlogs 40 to 60 years from now.

Unless such measures are taken now, we will have a shortage of sawlog-quality softwood a decade or so into the next century. The immediate problem is that both the material removed during thinning and much of the white spruce have no value except for adding some nutrients to the soil as they rot. Clearing and thinning operations cost money, and even though government is willing to pay a large part of the bill, many woodlot owners seem reluctant to undertake forest improvement activities if doing so will take money out of their pockets today. If, on the other hand, there was a market for the material removed, woodlot owners might actually make a little money—or at least break even.

It is here, in the creation of an expanded market for worthless wood, that biomass energy could play an important role in forest renewal. As this is written, at the end of the 1980s, the wood chip market appears to be the only possible market for this poor quality material.

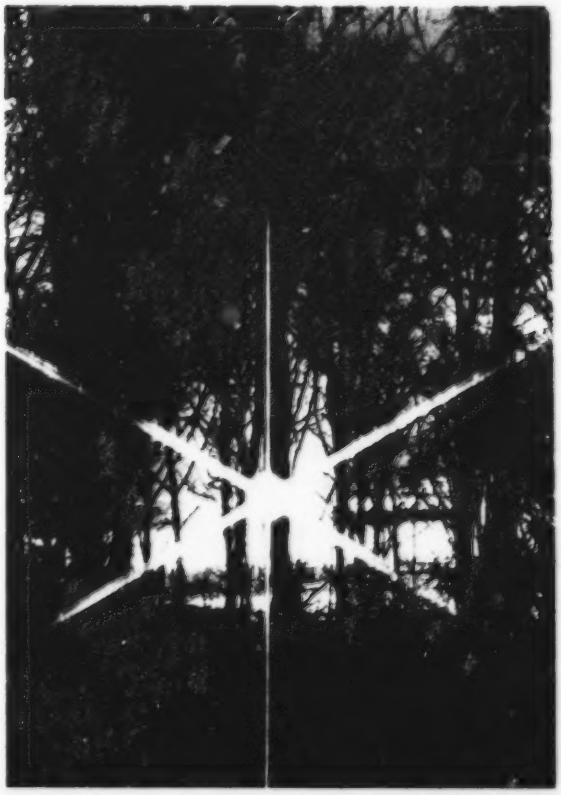
for wood chips would do much to improve the quality of the softwood resource. The reason for this becomes clear when we look at the overall situation.

A major long-term goal of the forest renewal effort is to grow more lumber-quality softwood, more "sawlogs." Two things currently stand in the way of this:

1. The overcrowding of young stands. (This creates small diameter trees of little commercial value.)
2. The large quantity of white spruce that will be maturing all at once during the next few years. (These are the naturally-seeded trees that grew on the farmland abandoned earlier in this century.)

To remedy the first situation, the overcrowded stands must be *thinned*. The best trees would be left uncut, and in 20 to 40 years (aided by the extra sunlight and growing room) they would become sawlog-quality trees.

To remedy the second situation, the mature, overmature, and poor quality stands of white spruce would be *harvested*. The sites would then be prepared, and



Also at this time, that market is too small to absorb all the low-grade material that needs to be harvested. To utilize that material, additional chip-consuming facilities would have to be built.

If such facilities were built, would there be enough wood *in the long run* to keep them operating? Let's assume that the 20-year forestry program is successful and the quality of our forest does improve dramatically. When Island woodlots eventually do produce more sawlogs and other high quality material, will there still be enough wood available for energy purposes?

The answer appears to be yes. Table 8.1 makes it clear that even when the resource is upgraded to produce more sawlogs and pulpwood, it will still produce about the same amount of *residual biomass*—unmarketable trees, tops, branches, and other harvest waste. This biomass residue has potential as wood-chip fuel, and the amount of such material is almost the same in both situations.

Maximum Even-Flow Sustainable Harvest from Island Forests

	Without Management (m^3/yr)	With Management (m^3/yr)
Sawlogs	58 000	141 000
Other merchantable wood	414 000	659 000
Residual biomass (wood chip potential)	1 073 000 (474 000 ODt)	1 070 000 (473 000 ODt)

(The figures include all types of wood, and assume that the resource is available for harvesting.)

Table 8.1

The "residual biomass" figures in Table 8.1 indicate that Island woodlots could sustain an annual harvest of wood for chips 47 times the 1988 demand of 10 000 Oven Dried tonnes (ODt). If chip-fueled co-generation systems producing a total 10 to 15 MW of electricity were built, the demand for chips might rise to as much as 125 000 ODt by the year 2005. Our woodlots could support almost four times even that demand. Given the figures above, it's hard to imagine that we could face a shortage of wood for chips.

Global Warming and Biomass Energy

Scientists, journalists, and others expressed considerable concern in the late 1980s about global warming, the greenhouse effect, and the emission of various "greenhouse gases"—particularly carbon dioxide (CO_2). What is the real story here, and how does biomass energy fit in? Is burning wood for energy part of the problem, or is it part of the solution? Let's look at several pieces of the puzzle.

Is the earth's atmosphere really warming up?

On a time scale of hundreds of years, yes. In the longer term, maybe not. The upper graph in Figure 8.1 shows the change in average global temperature from 1860 to 1987, based on worldwide measurements of sea and air temperature. The global temperature rose about 0.5 degrees during that period.

The lower graph shows the estimated average global temperature during the past 150 000 years (determined indirectly, of course). This graph indicates that much larger swings of temperature have occurred in the more distant past. Note, however, that the average global

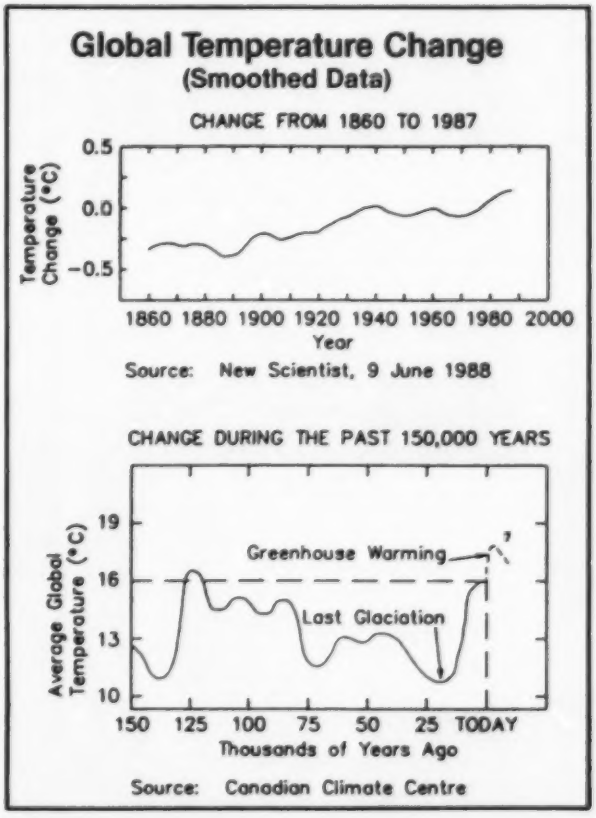


Figure 8.1

temperature during the last ice age was only five degrees Celsius below the present average temperature. Clearly, small changes in average global temperature can have large effects!

Regarding the future, a publication of the Canadian Climate Centre concludes:

> [Computer] models suggest that climate trends over the next few centuries will be dominated by an enhanced greenhouse effect. All indicate significant warming within the next 50 years, possibly by as much as an average of 1.5 to 4.5 degrees C over the entire earth's surface.
>
> [Studying examples of past climate change suggests] the warming of the next few hundred years could be followed by a long-term cooling trend. In 20 000 years much of Canada could again be covered by ice.

What does CO_2 have to do with the temperature rise?

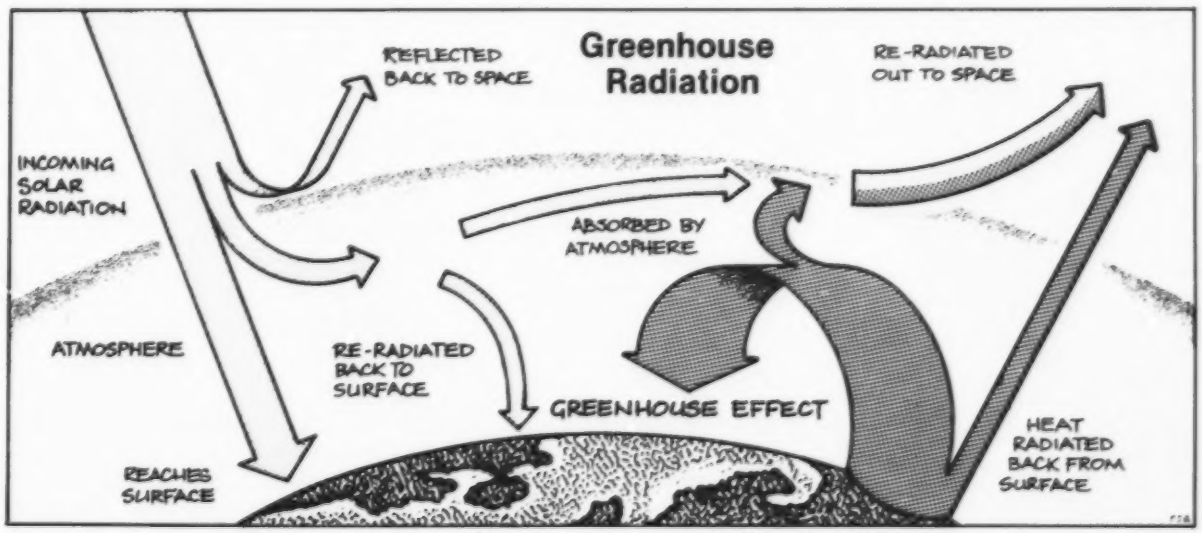
It gets warm inside a greenhouse because the glass lets the sun's energy in, but retards the escape of heat. In similar fashion, carbon dioxide gas in the atmosphere allows the sun's radiant energy to pass through to the earth, but inhibits the radiation of infra-red (heat) energy back into space. As a result, the temperature of the earth's surface is considerably warmer than it would be without the CO_2.

The atmosphere doesn't contain much CO_2—just 0.0330 per cent. The more CO_2 there is, however, the greater the greenhouse effect, and the hotter the earth gets. One computer model indicates that a doubling of the present CO_2 level would cause a two degree C rise in average global temperature.

How does the burning of fossil fuels tie in?

The present concern stems from the fact that atmospheric CO_2 levels are rising. At the beginning of the industrial revolution, the CO_2 level was only 0.0290 per cent. By 1960 it had reached 0.0314 per cent and was climbing fast. This present rapid rise is attributed to two causes: the burning of fossil fuels (coal, oil, and natural gas), and deforestation—the permanent removal of forest by burning, or cutting and burning. In one recent year (1980) the combustion of fossil fuels put an estimated 5.57 billion tonnes of CO_2 into the atmosphere. Deforestation probably released an equivalent amount.

Vegetation is a temporary storage place for atmospheric carbon. A tree, for example, uses the carbon contained in atmospheric CO_2 molecules to build cellulose and lignin molecules. When vegetation is burned, or decays, that carbon returns to the atmosphere once again as CO_2. Most scientists think that fossil fuels are the remains of vegetation that grew many millions of years go. By burning these fuels at



Carbon dioxide gas in the atmosphere allows the sun's radiant energy to pass through to the earth, but inhibits the radiation of infra-red (heat) energy back into space. As a result, the temperature of the earth's surface is considerably warmer than it would be without the CO_2.

the present high rate, human beings are putting huge amounts of carbon (as CO_2) back into the atmosphere over a very short time period. The immense amount of carbon that nature slowly withdrew from the atmosphere aeons ago is going back in an instant of geologic time.

Deforestation also involves the rapid release of stored carbon into the atmosphere. It is especially rapid in those many situations where great tracts of forest and jungle are being bulldozed to make pastures. Both the fossil fuel and deforestation type of CO_2 releases are bad because neither is balanced by an equivalent uptake of carbon in newly growing vegetation.

Is burning wood or other biomass any less damaging than burning fossil fuels?

Burning wood without growing new wood to replace it is deforestation—a serious part of the problem. It's very different, however, if the forest from which the wood is cut is renewed.

When trees mature they are either cut—with the wood being used for some human purpose—or they die of natural causes and decompose in the forest. In either case, new growth eventually fills in the hole in the forest. And regardless of what eventually destroys the wood—the slow action of fungi and bacteria or the fast action of fire—its carbon atoms return to the atmosphere.

The government of Canada has actively promoted international cooperation in dealing with atmospheric problems, and in June 1988 sponsored the *World Conference on The Changing Atmosphere: Implications for Global Security.* The conference was held in Toronto, and was attended by more than 300 world experts. One of those experts was Henry G. Hengeveld of Environment Canada's Canadian Climate Centre, a world authority on the atmospheric CO_2 problem. When asked whether biomass programs such as the one we have on P.E.I. are part of the CO_2 problem, or part of its solution, he was very clear:

> A managed wood program is contributing to the solution of the problem. If you burn wood from a forest, and are constantly regenerating that forest, it's a net zero. One of the recommendations that came out of the conference held last June was to reduce net CO_2 emissions into the atmosphere by 20 per cent over the next 17 years. Half was to come from energy efficiency and conservation programs, and half from fuel substitution programs—getting away from fossil fuels. In terms of bottom line, anything that's non-fossil fuel is [part of] a solution.

Wood Energy and Acid Rain

As mentioned in Chapter 1, acid rain and the damage it causes to lakes and forests are a consequence of burning coal and oil. The primary culprit is sulphur. The sulphur content of oil ranges from 0.3 to 7 per cent. The No. 2 furnace oil used for home heating is usually at the low end of this range, but the sulphur content of the heavy oils used for electrical generation and industrial heating is usually higher. The sulphur content of coal ranges from 0.5 to 7 per cent—with so-called "high sulphur coal" having over 5 per cent sulphur. When these fuels are burned, about 98 per cent of the sulphur in the fuel becomes sulphur dioxide (SO_2) emitted from the stack into the atmosphere. Typically this SO_2, in simple and complex chemical reactions, becomes dilute sulphurous and sulphuric acids in the water droplets of clouds.

What happens when *wood* is burned? There is good news on two counts. First, wood contains much less sulphur than coal or oil—only 0.02 or 0.03 per cent, one-tenth the sulphur content of low-sulphur oil and 1/200 that of high sulphur coal or oil. Second, because wood ash is strongly alkaline, it combines chemically with some of the SO_2, trapping it and keeping it from being emitted into the air. As a result, the SO_2 emissions from wood are lower than even the low percentage of sulphur would lead us to expect.

What of nitrogen oxides and other pollutants? Atmospheric nitrogen can combine with oxygen at high temperatures to form oxides of nitrogen—further contributors to the acid rain problem. Fortunately, wood-fired combustion units tend to emit lower quantities of nitrogen oxides than oil- or coal-fired units. This is because the temperature reached when wood is burned, while high enough to generate some nitrogen oxides (NO_x), is normally lower than with oil or coal combustion.

When wood is burned with the quite low temperatures and low air supply typically found in airtight stoves, smoke and various complex organic chemicals can be emitted. This has become a concern in some Yukon mountain valleys where, during periods of no wind and temperature inversion, the emissions from residential wood stoves can produce an objectionable level of air pollution. Our windy environment here makes this much less of an issue. Furthermore, all of the Island's chip-burning installations operate with ample oxygen and adequate temperatures, resulting in almost complete combustion. As a result, they emit little smoke, ash, or organic matter.

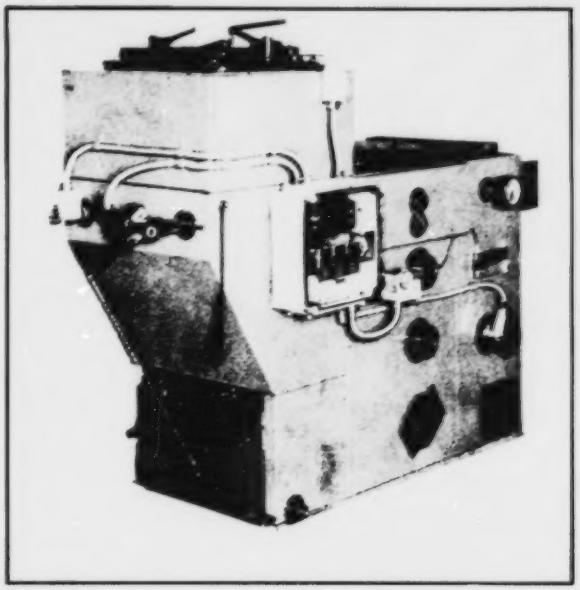
Some Possible Future Directions

Small Systems

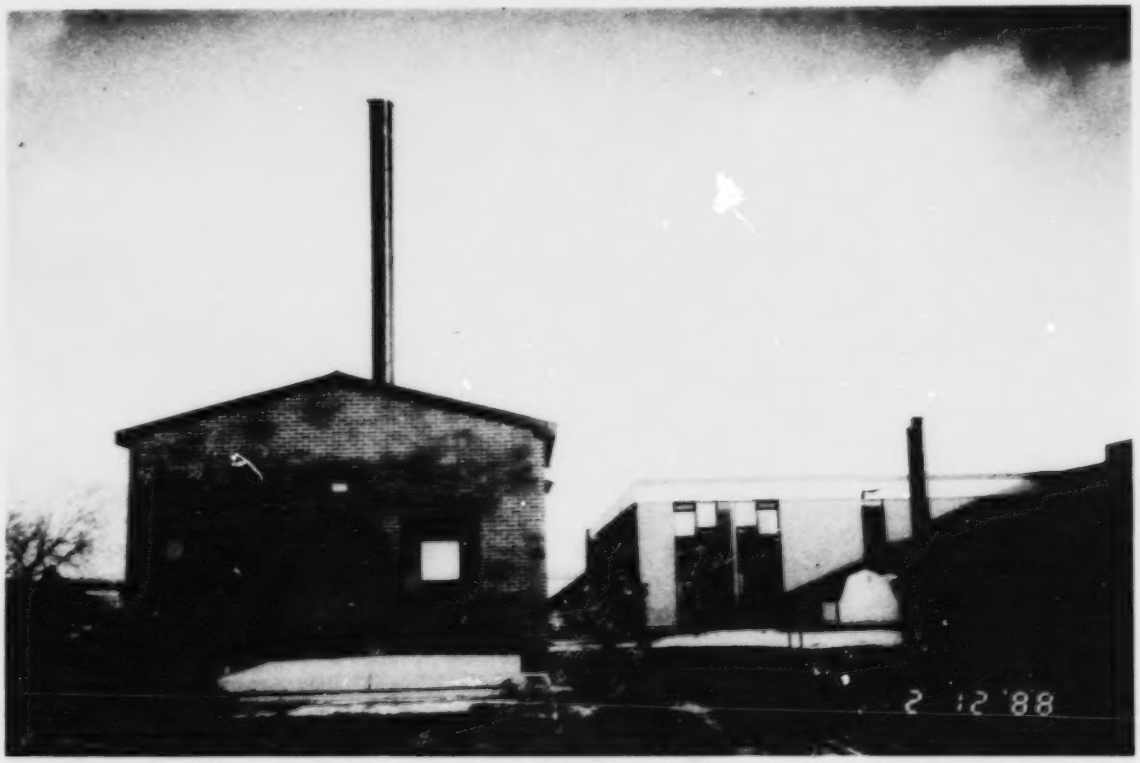
Wood chip systems for small institutional/commercial users and home owners presented a largely unsolved problem at the end of the '80s. The trouble, in short, was that such systems were too expensive.

Part of the problem was that many of the wood chip burning appliances installed during the '80s were one-of-a-kind, custom-designed products. Others were imported from Scandinavia with transportation costs, duties, taxes, and middle-man profits tacked on. The answer in the long run would seem to lie in clever cost-efficient designs and mass production here in Canada—if that proves feasible. An approach taken by the P.E.I. Energy Corporation in Prince County was to order several almost-identical systems at one time. This resulted in more efficient manufacturing and a lower cost per system—two steps in the right direction.

If small systems can't be built inexpensively, large combustion units will continue to be the focus of biomass activity here. And the wood heating of small facilities will be accomplished via district heating.



This Laka woodburning heating system was imported from Finland.



The brick building in the foreground of Westisle Composite High School houses a 700 kW wood-burning unit. The hatch cover for the wood chip fuel bin can be seen in front of the facility.

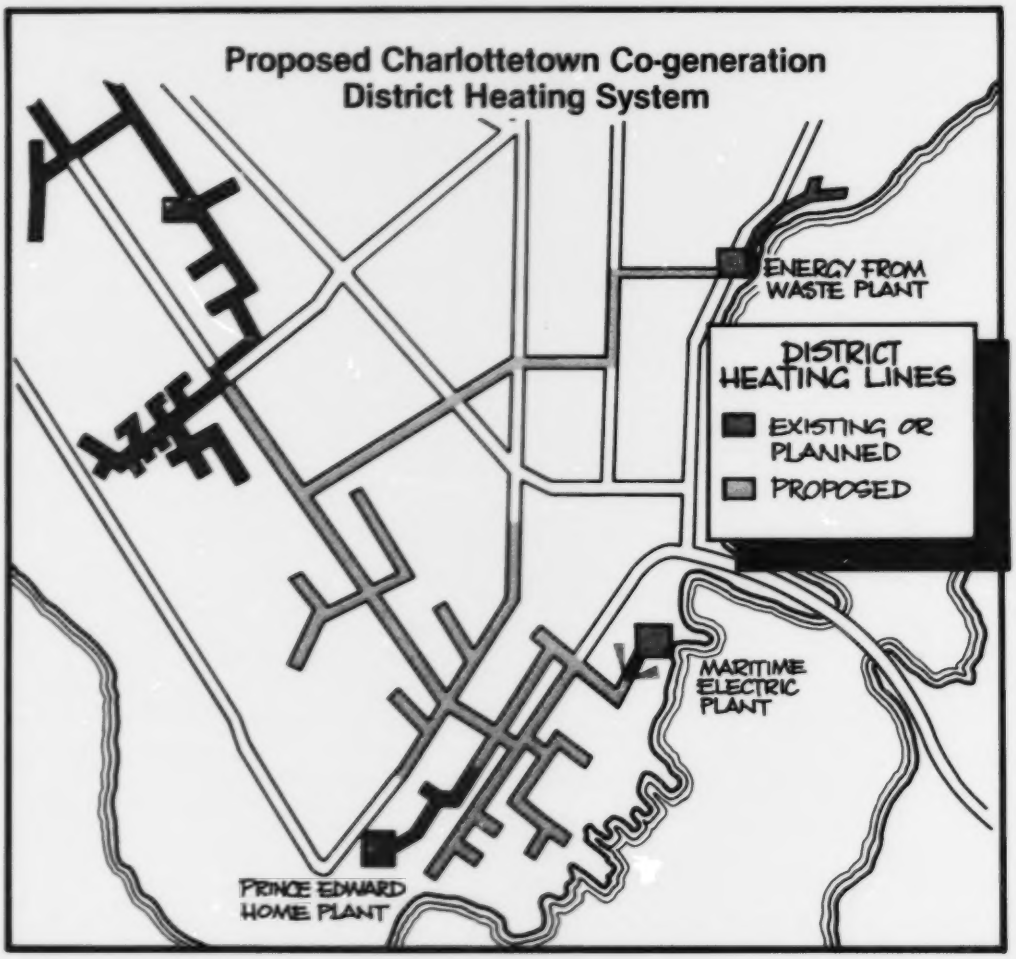
Co-generation

The idea of building one or more co-generation plants—large woodchip burning plants to produce both electricity and district heat—is attractive because this one action would solve several problems at once. The wood-chip requirement of such a plant (or plants) would raise the Island-wide wood chip consumption level to five or six times that of 1988. This much demand would put the wood chip industry on a solid footing, and is exactly what is needed to get that junk wood cleaned out of Island woodlots at a reasonably rapid rate. Then, too, a co-generation plant would solve the problem of acquiring more electrical generating capacity (a necessity in the early 1990s).

Wood chipper in action.

During the mid-1980s, the P.E.I. Energy Corporation carried out several feasibility studies on possible co-generation plants. Although at the time of the studies the economics did not appear attractive enough to proceed, P.E.I.'s eventual need for more electric generating capacity may well change that picture.

One promising possibility involves Charlottetown. In this scenario, a wood-fired co-generation plant would be built in the Charlottetown area, and district heating there would be expanded. The U.P.E.I. and downtown District Heating (DH) systems would be interconnected and enlarged, and could be linked to the energy-from-waste facility. Subscribers with as little as 20 kW demand would be eligible to connect to the system, and the 40 or so district heating subscribers served by the present systems would increase to about 410 subscribers over time. 19 700 metres of DH carrier pipe would be added to the present 7300 metres, bringing the total to 27 000 metres.



In one of the co-generation proposals being considered, waste heat from a wood-fired electrical generating plant would heat Charlottetown buildings in an expanded district heating system.

PROBLEMS

Solving Some Co-Generation Problems

The following problems refer to the proposed Charlottetown co-generation system just described. Solve them using the figures given in the write-up. Assume that the net energy content of a tonne of green wood is 10^{10} joules. (That's the energy still available *after* the moisture has been driven off.)

1. If 410 subscribers are all that could be put on the district heating system without their heat demand exceeding the maximum output of the plant, what would be the average heat demand per subscriber?

2. If all DH subscribers had the minimum allowable demand of 20 kW, how many subscribers could the system support?

3. On cold winter days when all the heat produced by the co-generation plant is consumed by the district heating system, the overall efficiency of the system (useful output energy / input energy) would be above 70 per cent. Using the figures given in the text, calculate the efficiency of the co-generation plant *averaged over an entire year.* Why is this figure lower?

Maximum output of the co-generation plant would be approximately 10 MW of electricity and 40 MW of heat. In the course of a year it would supply 68 000 MWh of electrical energy, and 96 000 MWh of heat energy. The total capital cost for the entire project would be $44 million, and the annual consumption of wood chips would be 128 000 green tonnes.

There are many good reasons for considering the co-generation route. More imported oil would be displaced by readily-available, home-grown biomass. This would make the Island a bit more energy independent. It would create more local jobs. It would keep more dollars in the local economy. It would significantly aid current effort to upgrade the Island's forests. And the shutdown of many small oil burners would reduce air pollution. Among potential subscribers, interest in district heating is greater than ever—and for good reasons. Subscribers get reliable heat at a fair price, with no boiler replacement or maintenance expenses.

Preliminary estimates indicate that an Island-based co-generation plant could generate electrical power at rates competitive with the cost of off-Island generation. It appears to be a good option from the utility customers' perspective, and with all the socio-economic benefits, a very good option for the Island as a whole. Using our low-grade forest biomass to co-generate electricity and heat is an exciting possibility for the future.

Sustainable Development

This final chapter brings us full circle, back to the concerns raised in Chapter 1 — concerns about the well-being of people, appropriate energy use, and environmental impacts. During the weeks you have spent exploring Prince Edward Island's energy situation, you have also been gaining insight into difficult matters that extend far beyond our island's shores. You have touched on many aspects of what has come to be called *sustainable development*—perhaps without realizing it.

The term was popularized by the 1987 report, *Our Common Future,* which was prepared after three years of work by the World Commission on Environment and Development (WCED). There is perhaps no better way to end this unit than to share with you some of the statements made in that report, and let you and your classmates think about them and discuss them.

Until recently, the planet was a large world in which human activities and their effects were neatly compartmentalized within nations, within sectors (energy, agriculture, trade), and within broad areas of concern (environment, economics, social). These compartments have begun to dissolve. This applies in particular to the various global "crises" that have seized public concern, particularly over the past decade. These are not separate crises: an environmental crisis, a development crisis, and energy crisis. They are all one.

Ecology and economy are becoming ever more interwoven—locally, regionally, nationally, and globally—into a seamless net of causes and effects.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

...sustainable development requires the promotion of values that encourage consumption standards that are within the bounds of the ecologically possible and to which all can reasonably aspire.

Sustainable development requires that the rate of depletion of non-renewable resources should foreclose as few future options as possible.

...sustainable development requires the conservation of plant and animal species.

Sustainable development requires that the adverse impacts on the quality of air, water, and other natural elements are minimized so as to sustain the ecosystem's overall integrity.

Meeting essential needs requires not only a new era of economic growth for nations in which the majority are poor, but also an assurance that those poor get their fair share of the resources required to sustain that growth.

The period ahead must be regarded as transitional from an era in which energy has been used in an unsustainable manner.

The Commission believes that there is no other realistic option open to the world for the 21st century [than to opt for a low-consumption, energy efficient future]. The ideas behind these lower [consumption] scenarios are not fanciful. Energy efficiency has already shown cost-effective results.... Properly managed, efficiency measures could allow industrial nations to stabilize their primary energy consumption by the turn of the century. They would also enable developing countries to achieve higher levels of growth with much reduced levels of investment, foreign debt, and environmental damage.

How can P.E.I. meet its immediate energy needs while ensuring that future generations will be able to meet theirs? As we have seen, it is a question with no final or absolute answers. Nevertheless, it will be one of the most important questions that your generation will face. A willingness to accept and wrestle with its complexity, and the uncertainties that surround it, will be essential if you are to find an optimum answer.

"Energy is, put most simply, the fundamental unit of the physical world. As such, we cannot conceive of development without changes in the extent or nature of energy flows. And because it is so fundamental, every one of those changes of flows has environmental implications. The implications of this are profound. It means that there is no such thing as a simple energy choice. They are all complex. And they all involve trade-offs. However, some of the choices and some of the trade-offs appear to be unequivocally better than others, in the sense that they offer more development and less environmental damage."

David Brooks
Friends of the Earth
WCED Public Hearings
Ottawa, 26-27 May 1986

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To the Memory of A. Kenneth Bell

P.E.I. Museum & Heritage Fdn. (1989)

Petroleum Economist, The International Energy Journal

Our Common Future, c.1987, Oxford University Press

John TeRaa, 107

P.E.I.P.A.

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